Chemical Integrity of Naturally-occurring Substances in the Great Lakes

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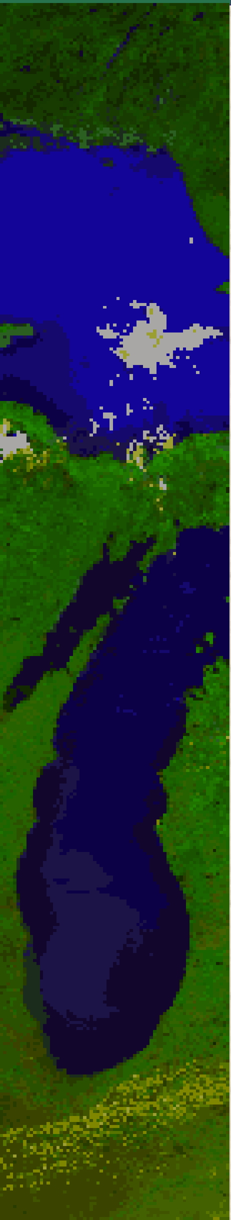

Acknowledgements

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- SUNY – CESF
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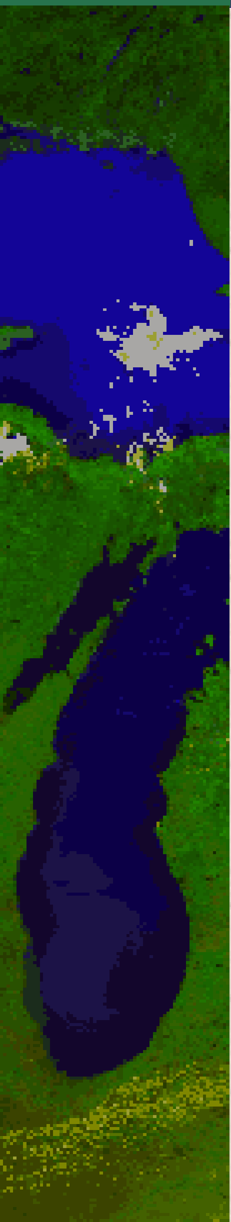
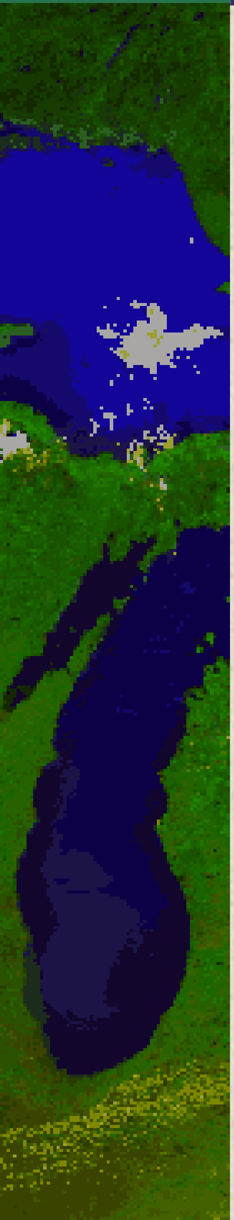
- New York Sea Grant
  - Helen Domske, NYSG specialist

Presentation Outline

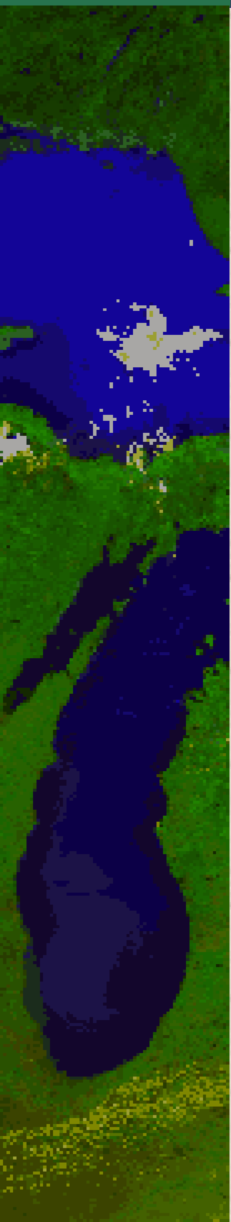


- Naturally-occurring Substances
- Chemical Integrity Analysis Logic
- How to manage phosphorus in a changed Great Lakes ecosystem?
- Are there undesirable trends in general water chemistry?
- What bio-toxins should we worry about?

Categories of Naturally-occurring Substances



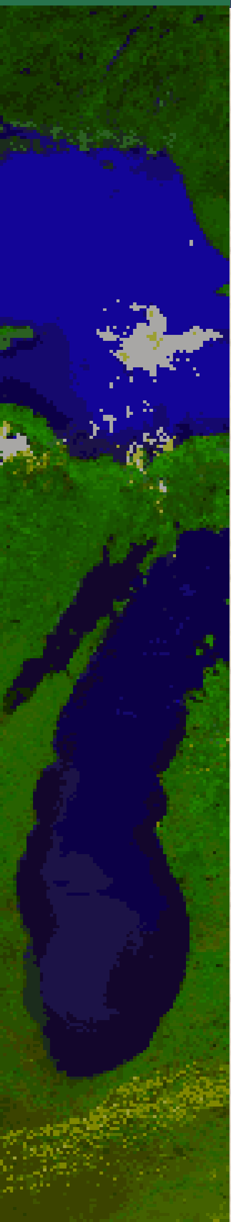
- **Nutrients and eutrophication**
  - Macro-nutrients (P, N, Si)
  - Micro-nutrients (Fe, Zn, etc.)
  - Chlorophyll *a*
  - Dissolved oxygen
- **Metals (Pb, Cd, Hg, etc.)**
- **General water chemistry**
  - Major ions/salinity/hardness
  - pH – Alkalinity – DIC system
- **Taste/odor compounds (MIB, geosmin)**
- **Biota-produced toxins**
  - Cyanotoxins
  - *Botulinum* toxins



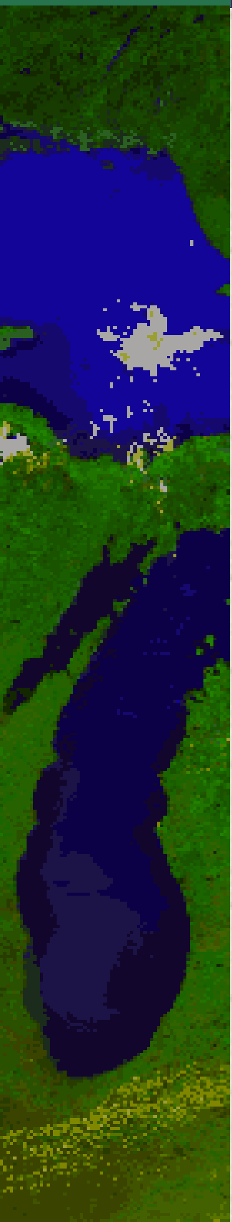
Sources of Naturally-occurring Substances

- Naturally occur in earth's crust
  - Leached and eroded from soil
- Formed by natural chemical and biochemical reactions in soil, water, sediments
- Humans can accelerate cycling and entry into the Great Lakes
  - Mining and application of road salt
  - Mining and manufacturing processes
  - Application of fertilizers
  - Creation of conditions that accelerate natural chemical and biochemical reactions

What is Chemical Integrity?

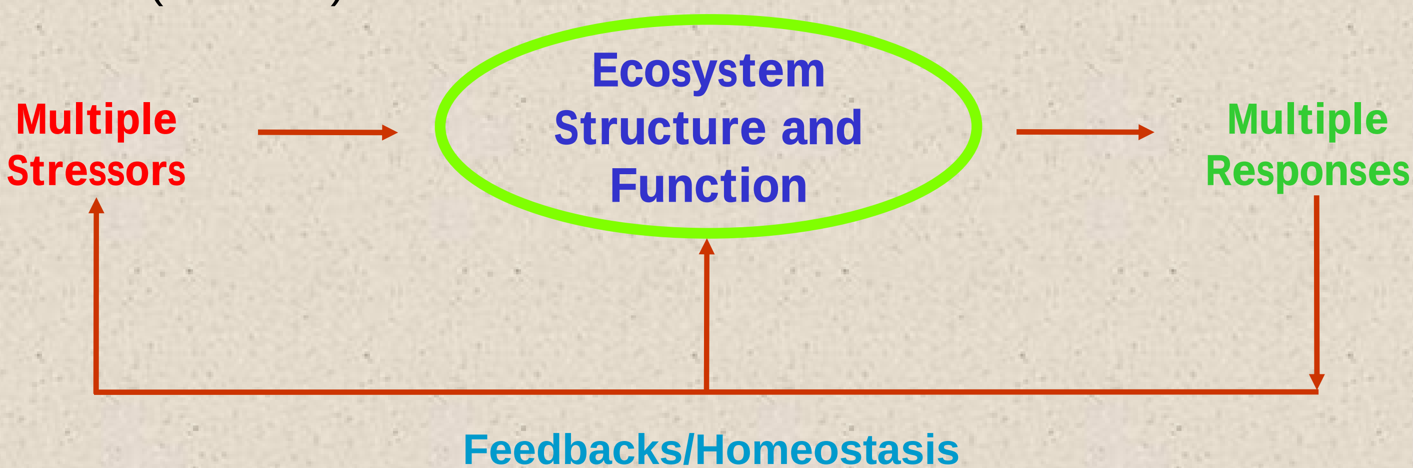


- **Chemical Integrity of the Great Lakes**
  - **The chemical composition of a lake ecosystem that provides all of the chemical needs for that system to maintain overall *ecosystem integrity*.**
  - **Chemical concentrations are bounded such that there is not too much or too little relative to other chemicals and relative to the ecosystem's needs for maintaining its integrity.**
- **Chemical integrity must be understood and evaluated in terms of <u>sources, loadings, transport, fate, and ecological effects</u> (humans are part of the ecosystem).**

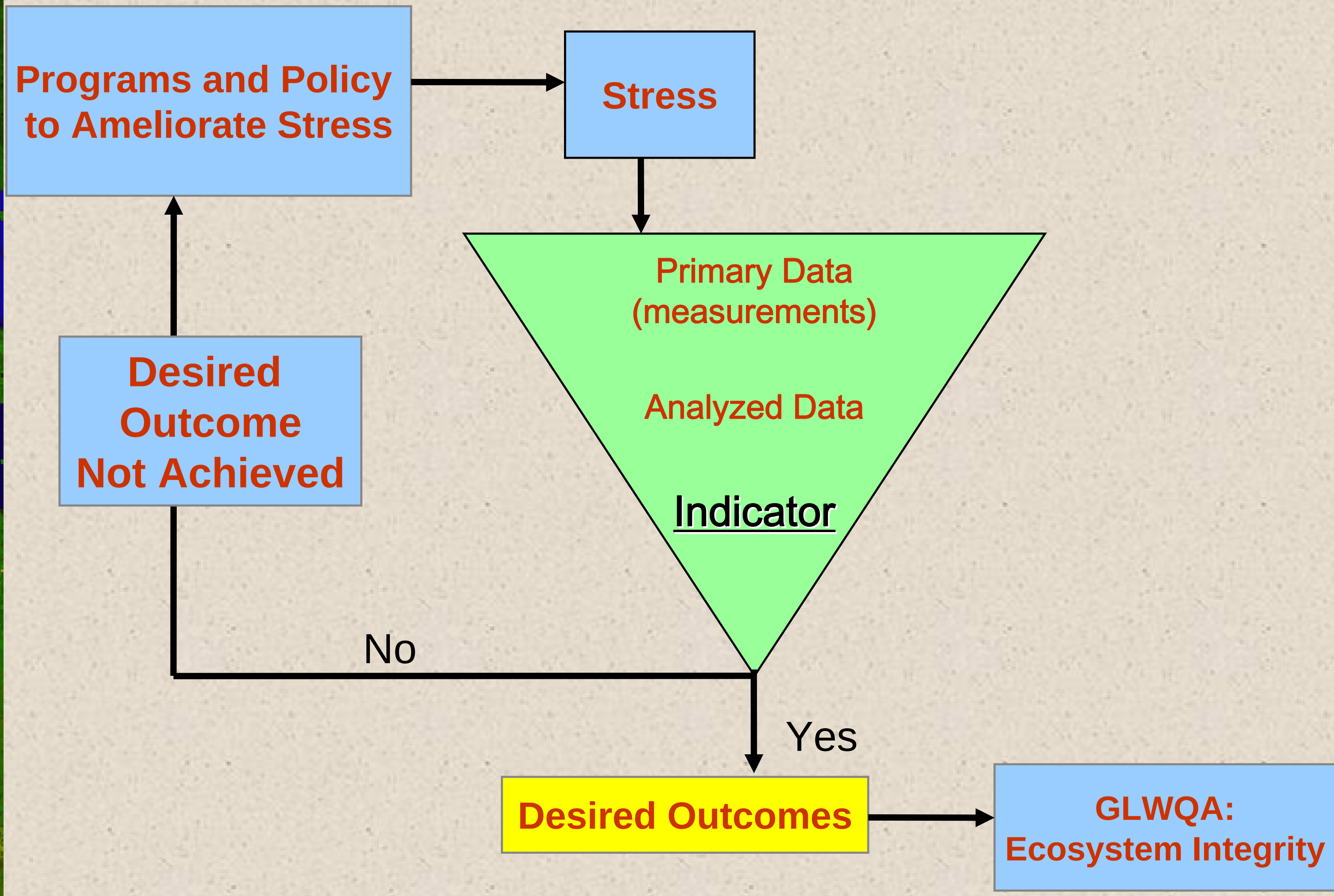


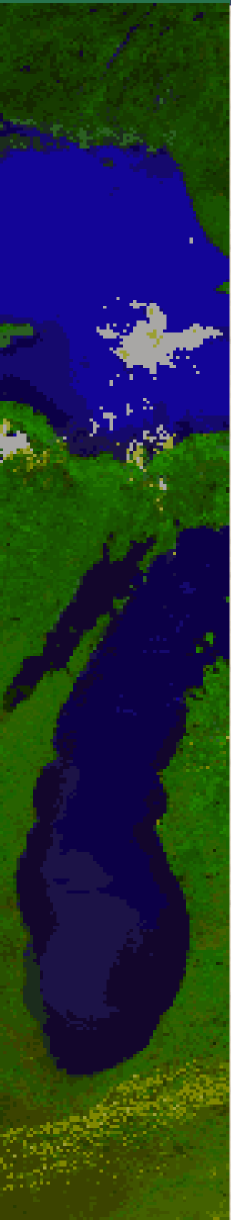
What is Ecosystem Integrity?

- An aquatic ecosystem is judged to have integrity when its physical, chemical, and biological structure is such that it is functioning as a complete and healthy ecosystem.
- “Complete” and “healthy” can only be determined in terms of indicators of that ecosystem’s performance relative to a performance goal
- Measures of ecosystem performance
  - Biologically diverse/complexity
  - Evolving toward a more stable system
  - Resilience/Homeostasis
    - resistance to irreversible change in response to external perturbations (stressors)



Framework for Evaluating Ecosystem Integrity (from IETF-IJC)

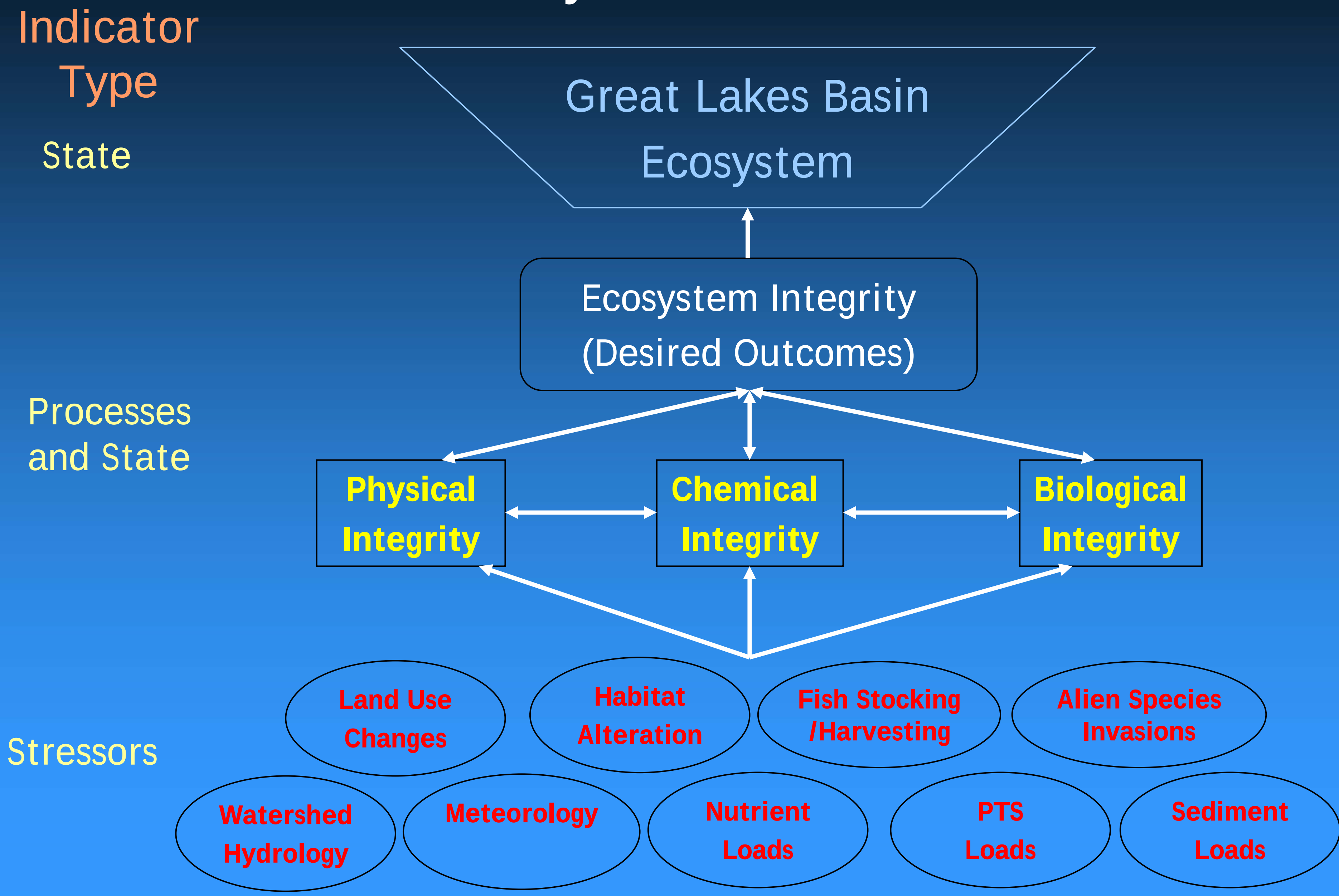




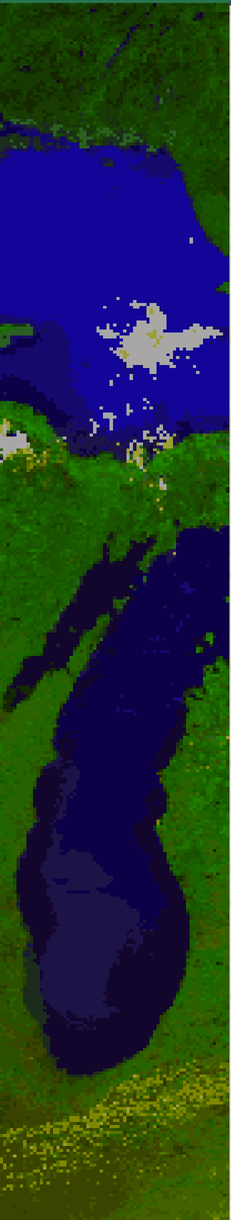
Indicators of Ecosystem Performance

- **Ecosystem Indicator: A measurable feature, or one derivable from measurements, which singly or in combination provides managerially and scientifically useful evidence of ecosystem integrity, or reliable evidence of progress toward one or more ecosystem objective.**
  - **Indicator can be a physical, chemical, or biological measurement that can be related in a meaningful and understandable way to ecosystem performance.**
  - **Indicator can be a *stressor*, a *process*, or a system *state variable***
- **Ecosystem models are a tool for relating indicators to ecosystem performance.**

Model for Measuring and Understanding Ecosystem Health



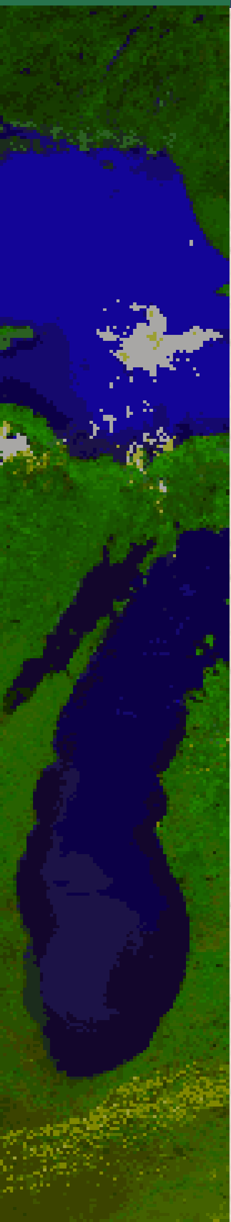
Nutrients and Eutrophication

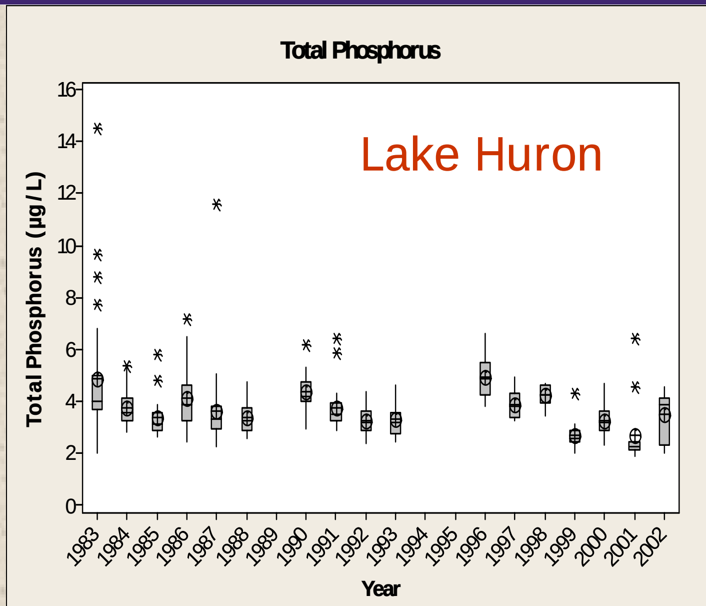


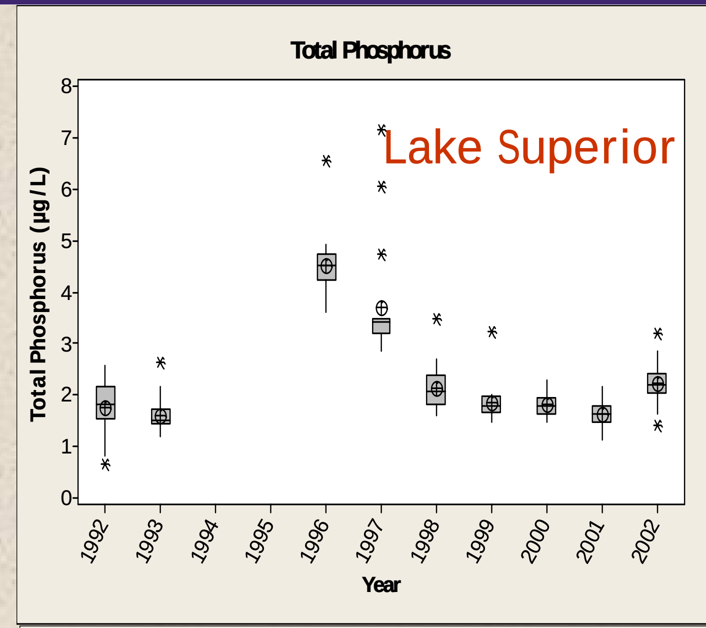
- Phosphorus is limiting nutrient and is controlled in Great Lakes
- Nitrogen (as N/P ratio) can impact algal speciation
- Phosphorus management in 1970's and '80s was based on chlorophyll *a* targets
  - Very successful outcome
- Now other factors raised as issues in P control
  - Fish production
  - Invasive species impacts
  - Still seeing water quality impacts in Lake Erie - hypolimnion DO

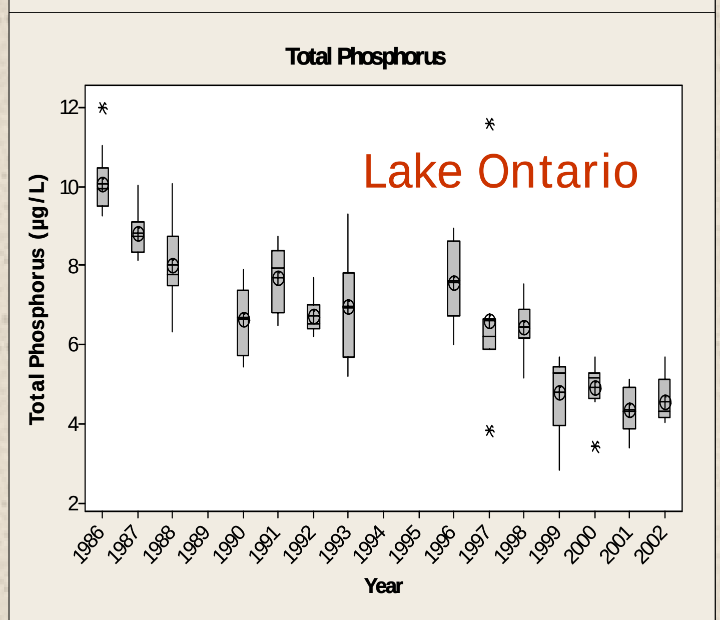
Total Phosphorus Trends in Great Lakes

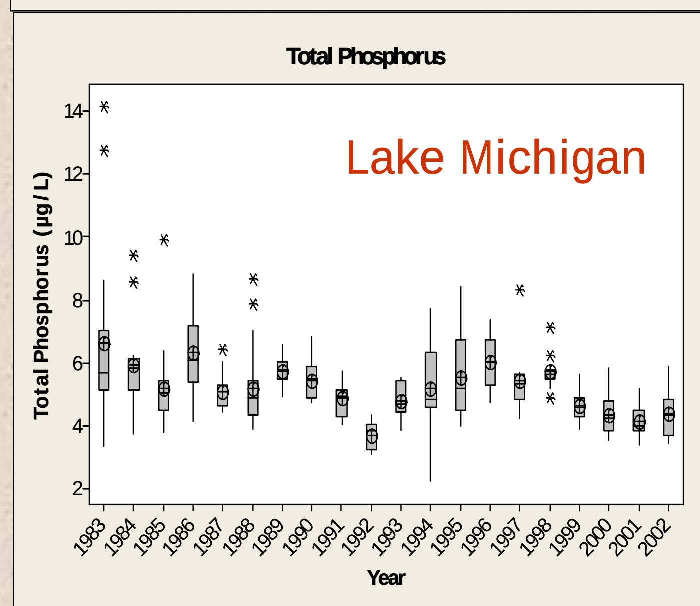
(GLNPO spring data)





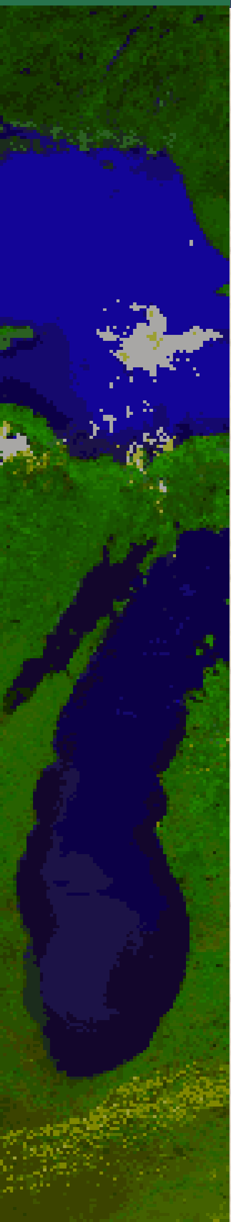


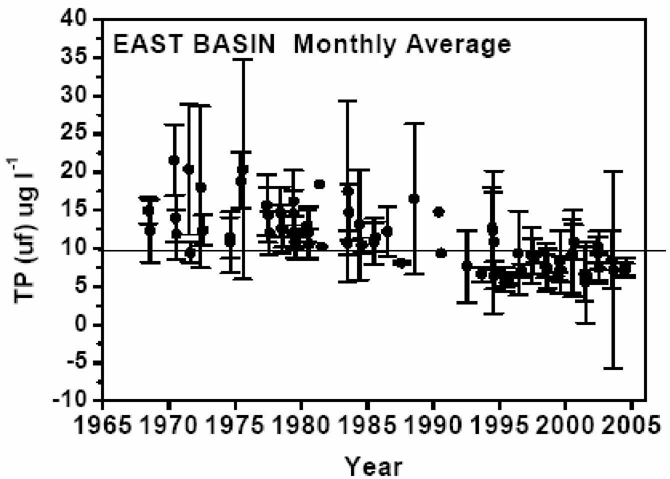


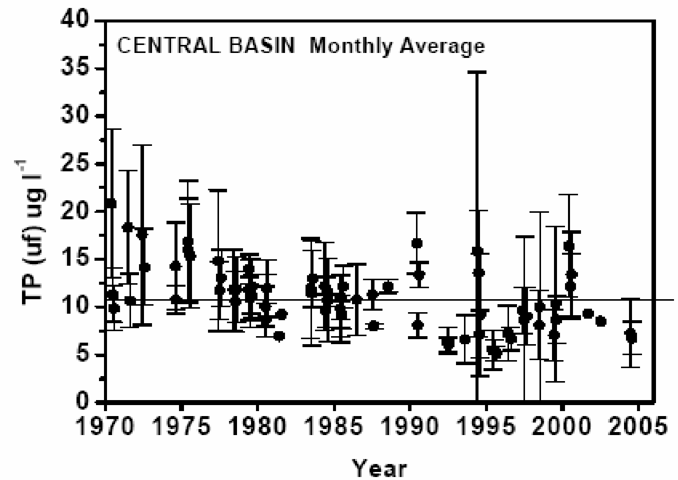


Environment Canada TP Data for Lake Erie

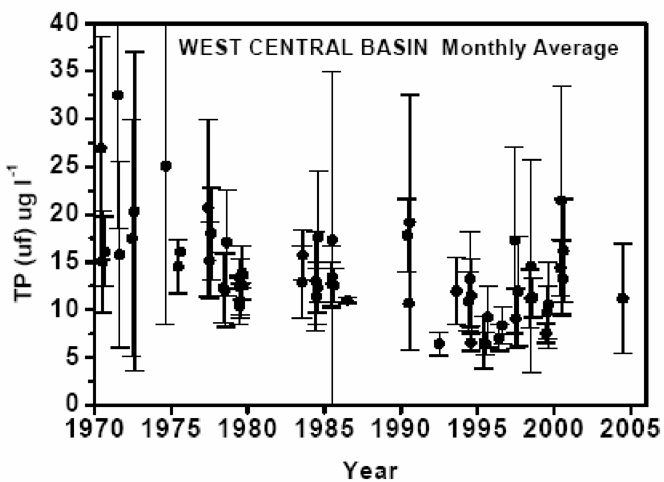
(Charlton, 2005)

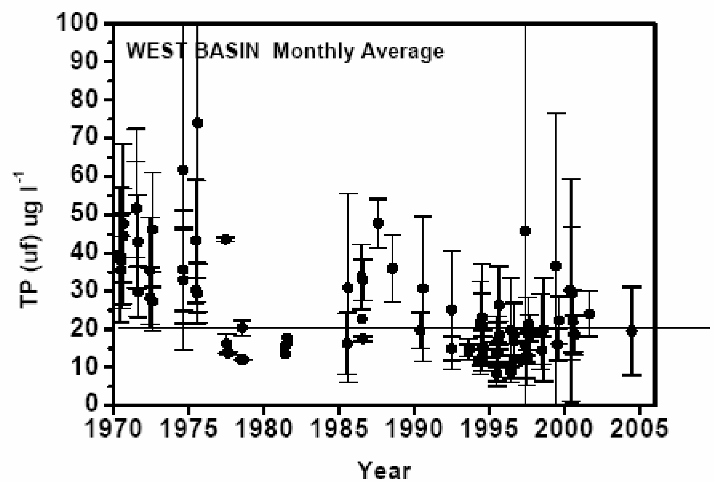




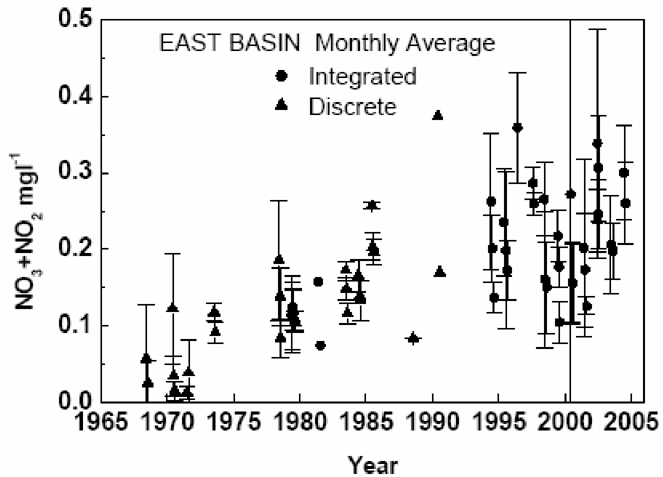


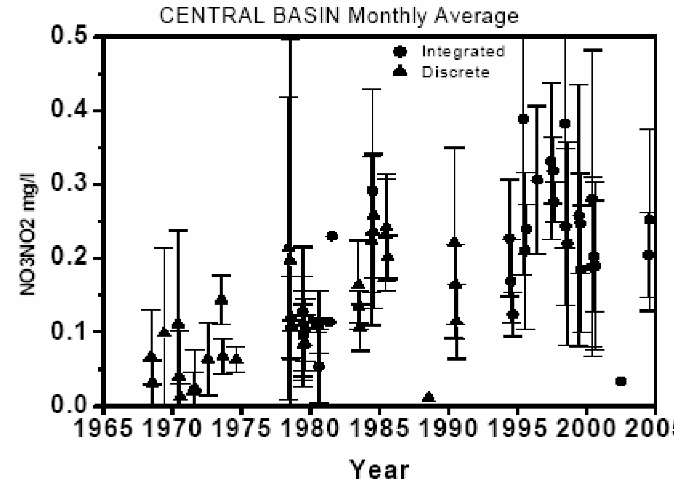
Phosphorus, a key nutrient for algae growth



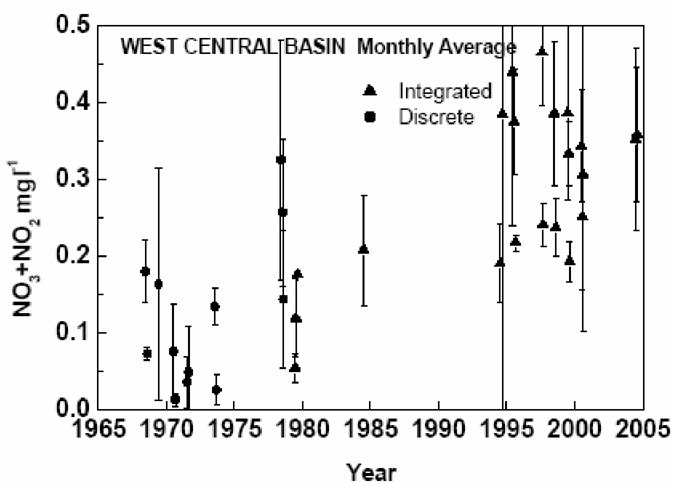


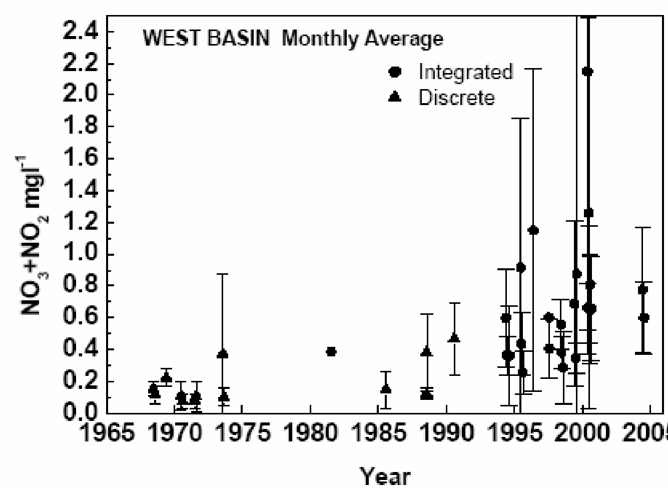
Environment Canada NO_3-NO_2 Data for Lake Erie (Charlton, 2005)



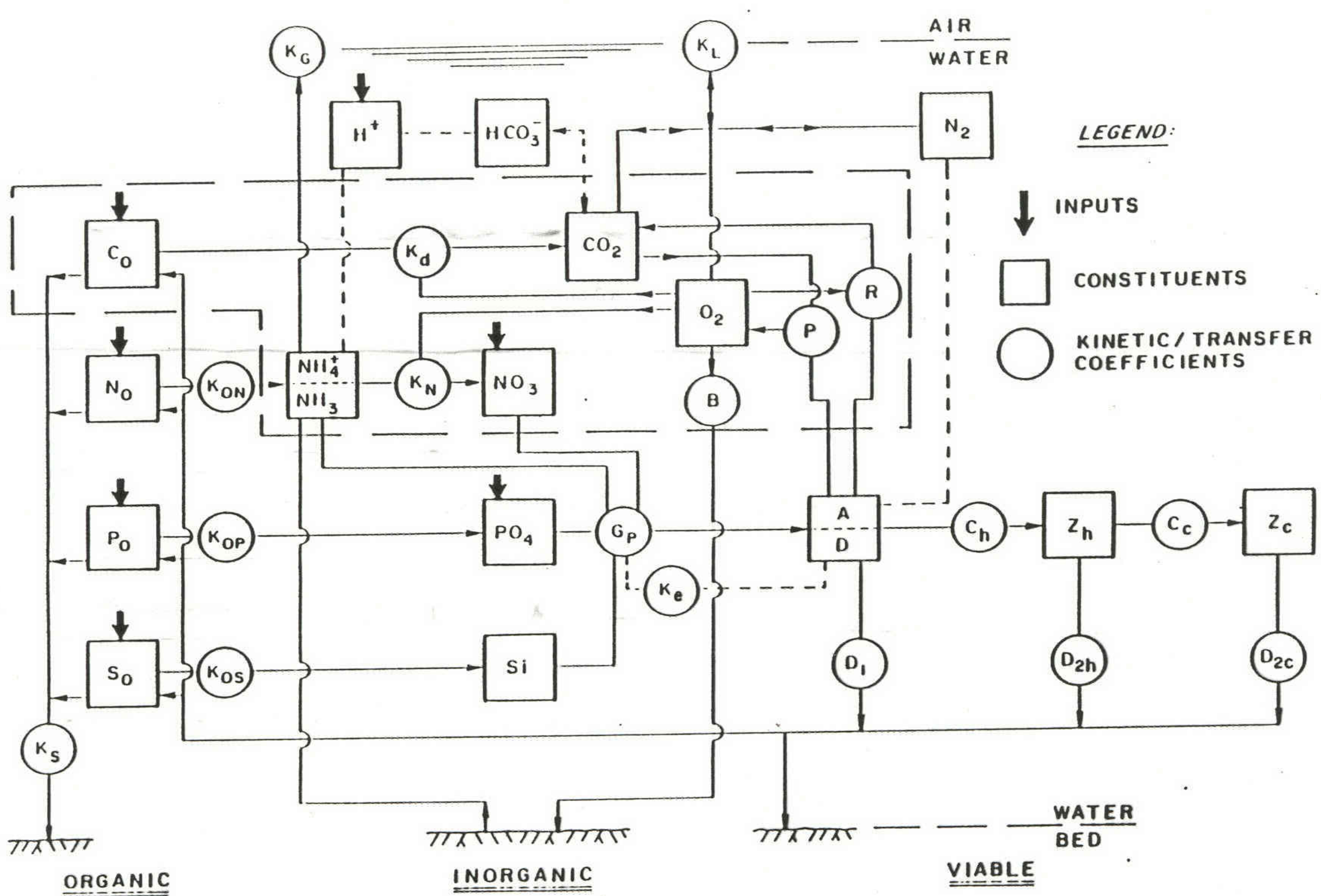


Nitrogen nutrient not controlled much in sewage, also in fertilizer

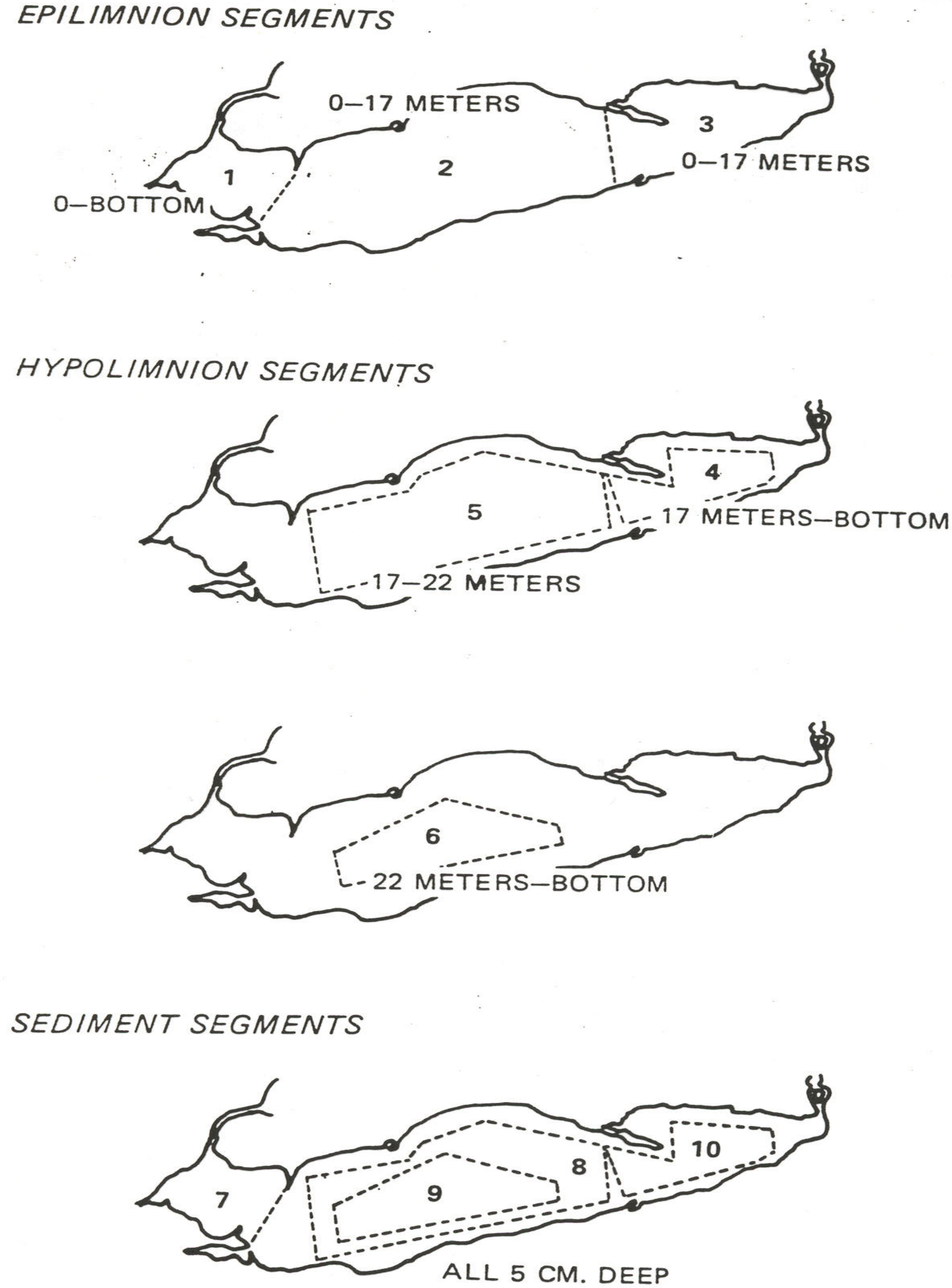


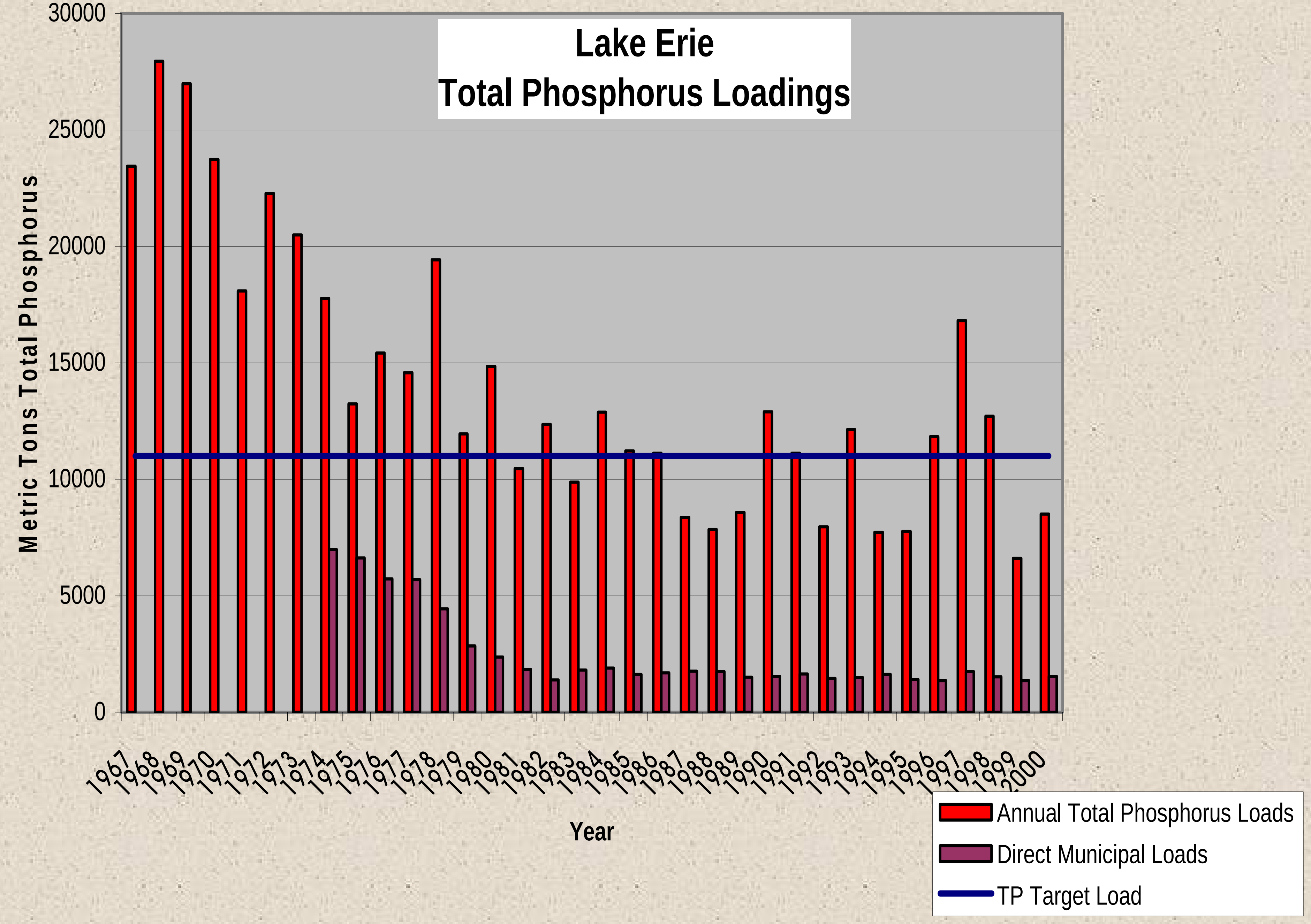


DiToro, et al. Lake Erie Eutrophication Model (1976)



Segmentation for 1976 Lake Erie Model




Lake Erie
Total Phosphorus Loadings
Metric Tons Total Phosphorus
30000
25000
20000
15000
10000
5000
0
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
Year
Annual Total Phosphorus Loads
Direct Municipal Loads
TP Target Load

Lake Erie Model Post-audit (Chl *a*)

(DiToro, et al. 1987)

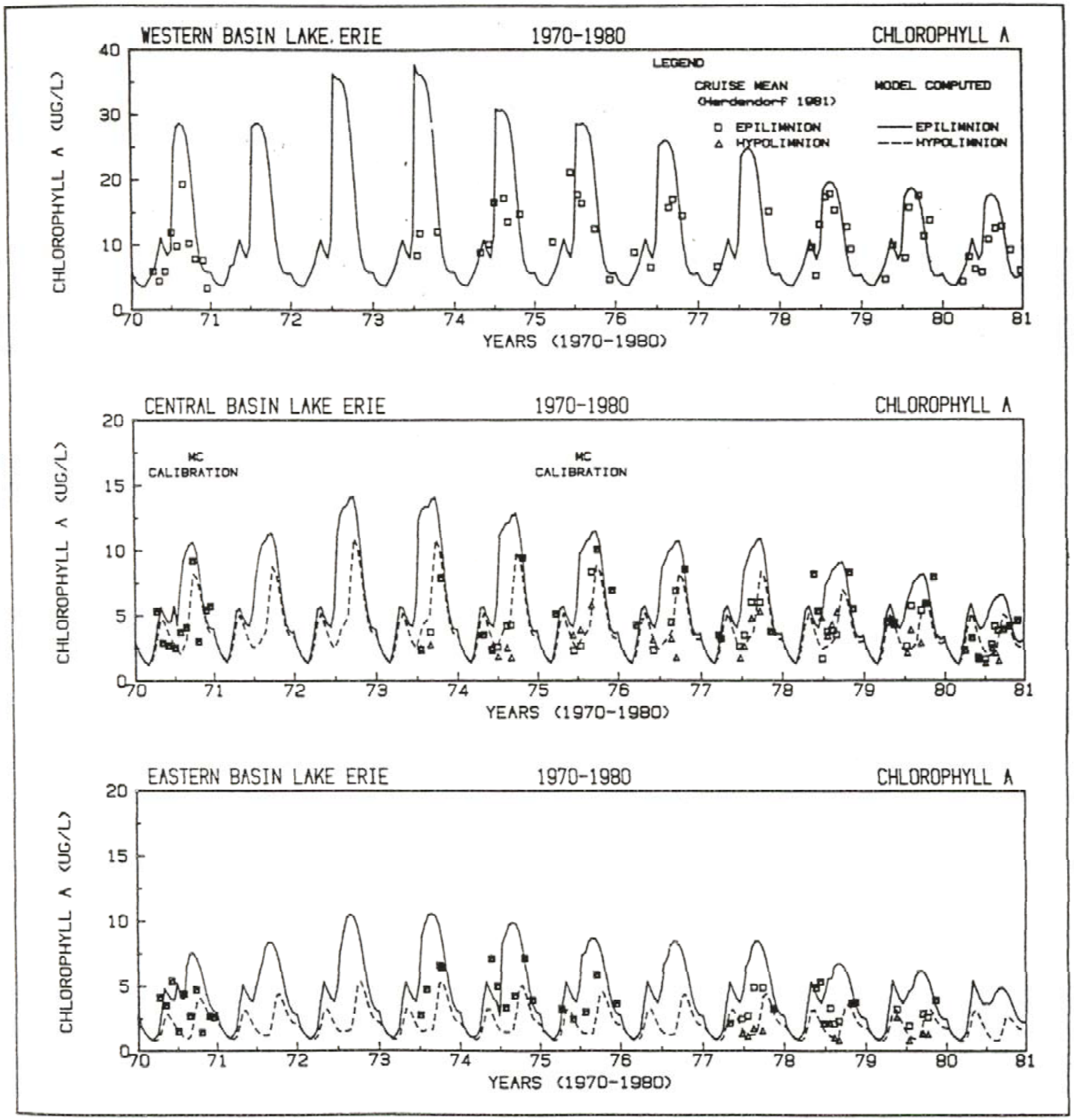
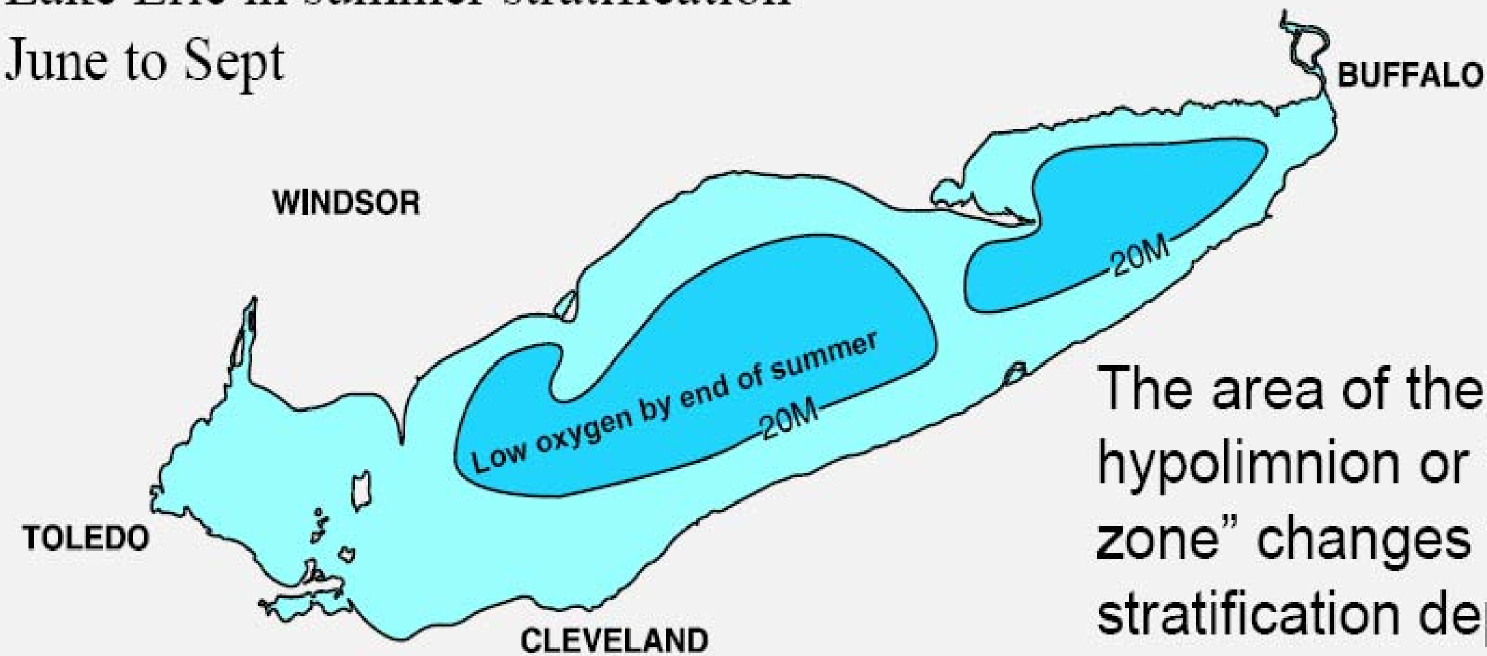
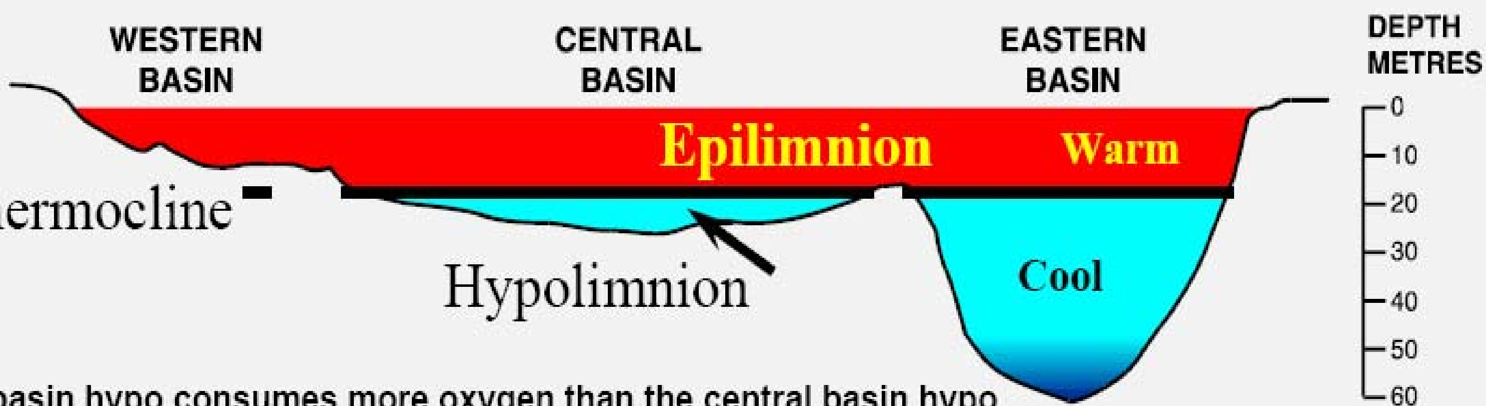


FIG. 10a. Comparison of model predicted and 1970 to 1980 observed cruise mean chlorophyll a *— western, central, and eastern basins of Lake Erie.*

Lake Erie in summer stratification
June to Sept



The area of the hypolimnion or "dead zone" changes with stratification depth and date.

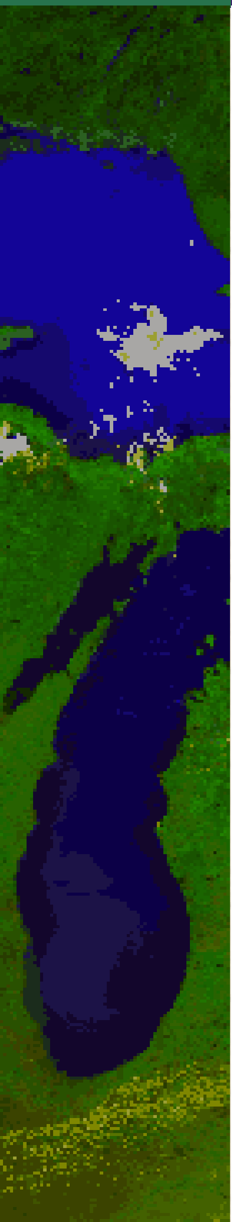


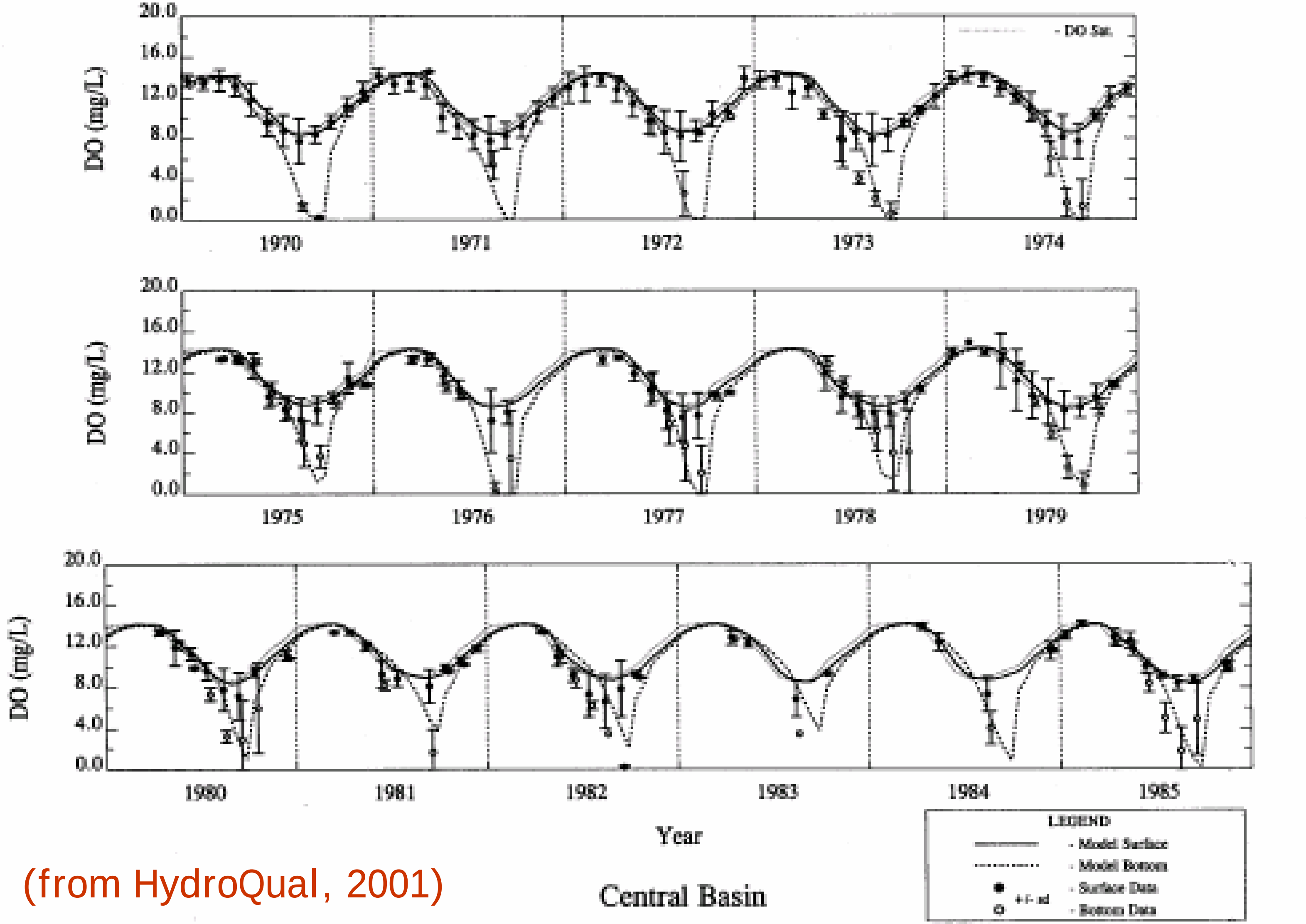
The east basin hypo consumes more oxygen than the central basin hypo

LAKE ERIE LONGITUDINAL CROSS SECTION

(from Charlton 2005)

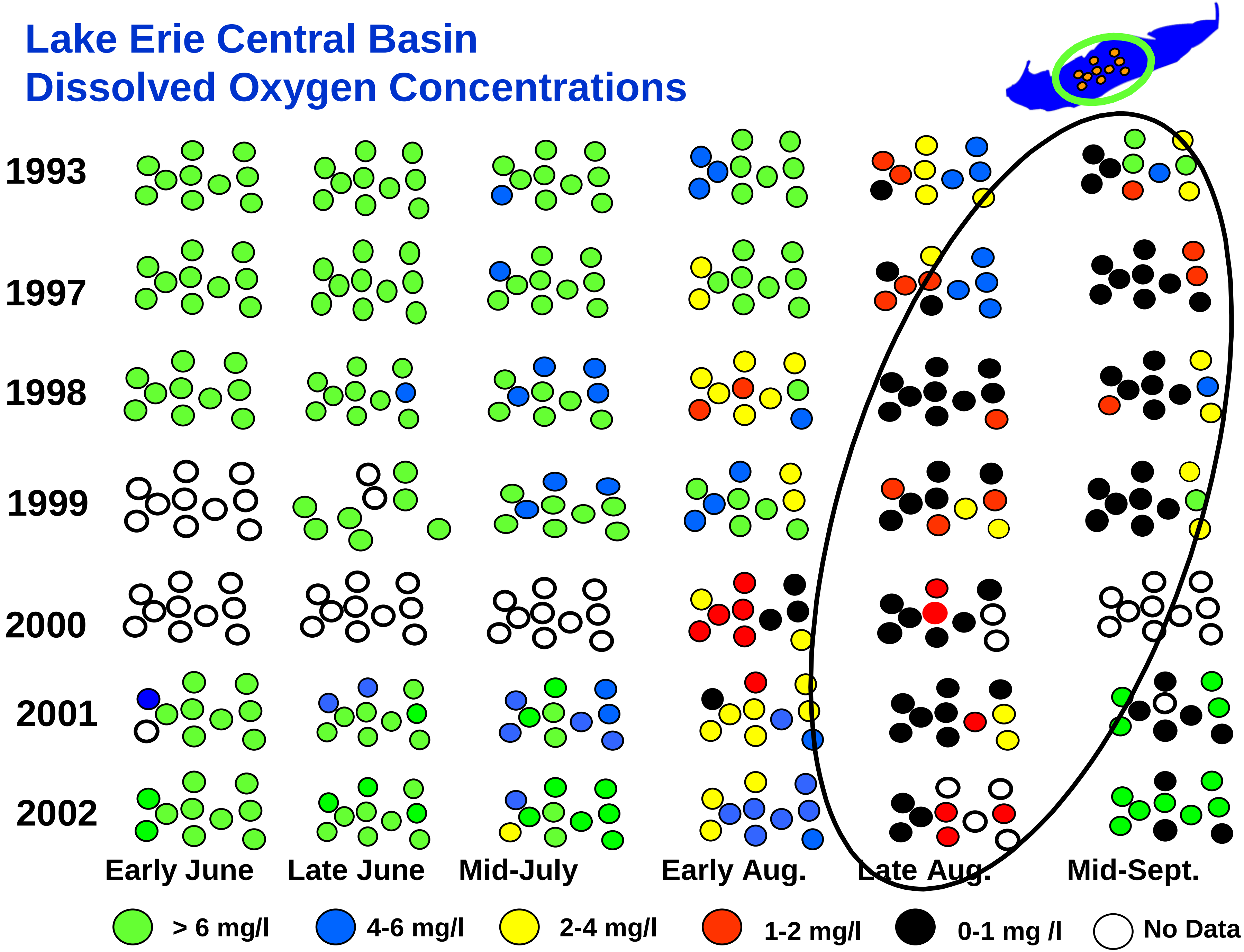
Lake Erie Model Post-audit
(tested through 1985)



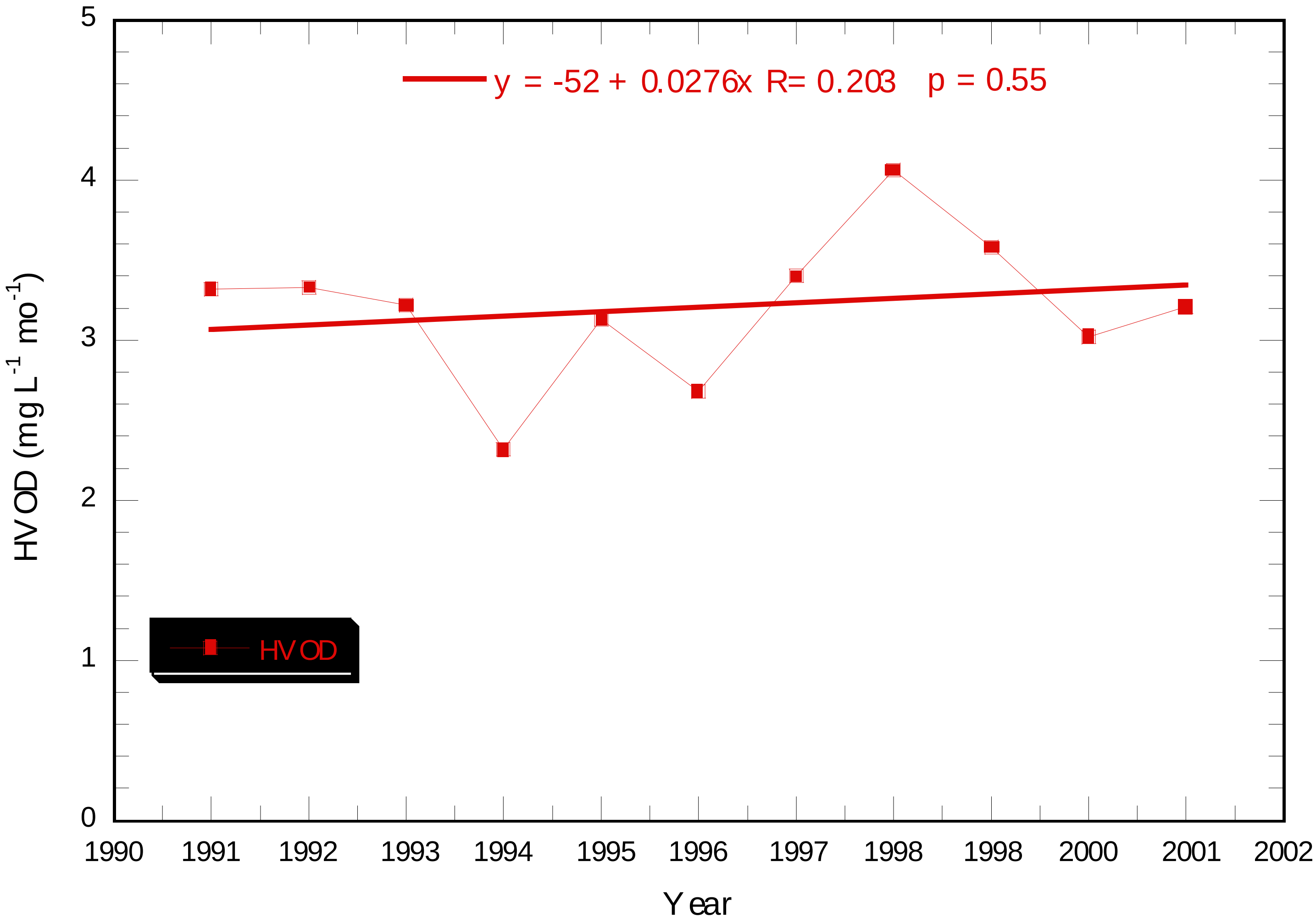


(from HydroQual, 2001)

Lake Erie Central Basin
Dissolved Oxygen Concentrations



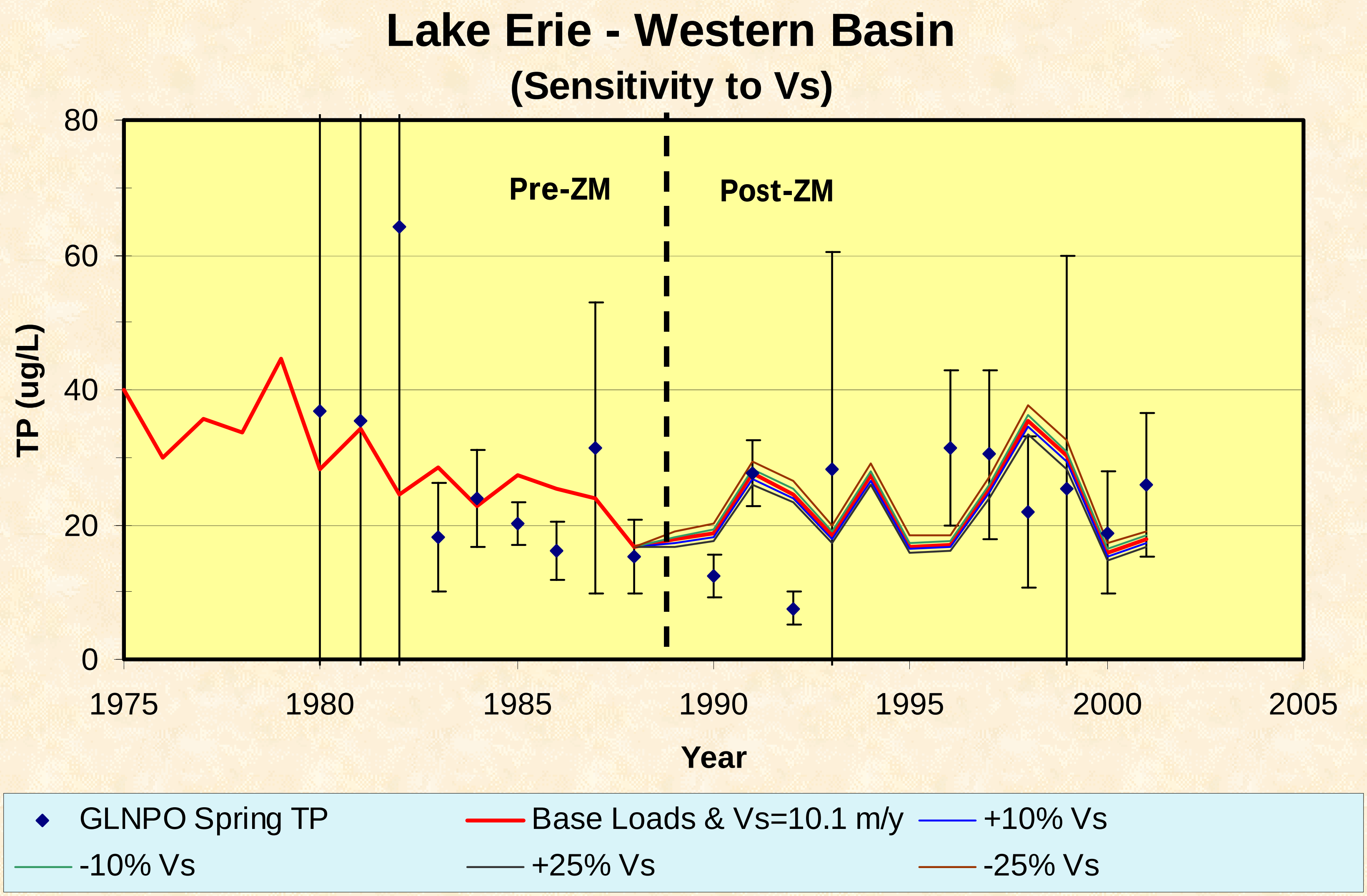
HVOD rates for the Central Basin from 1991 to 2001 corrected for temperature, vertical mixing and hypolimnion thickness.



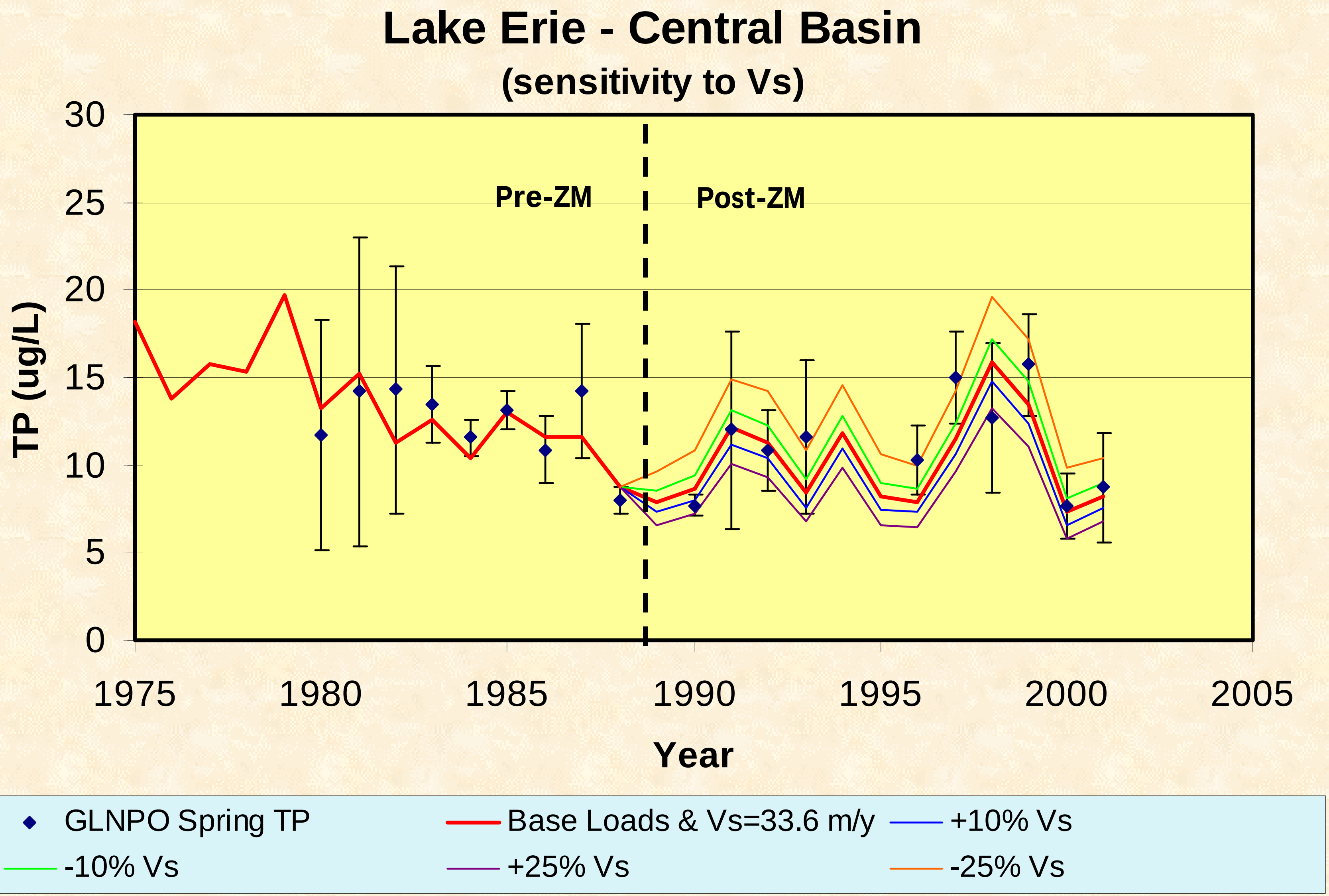
Hypothesis

- There is always zebra mussels
- Due to a de-coupling of the phosphorus-chlorophyll *a* relationship in Lake Erie caused by the *Dreissena* invasion, the ***net loss rate of total phosphorus from the water column*** (*i.e.,* net apparent phosphorus deposition rate to sediments) has decreased.

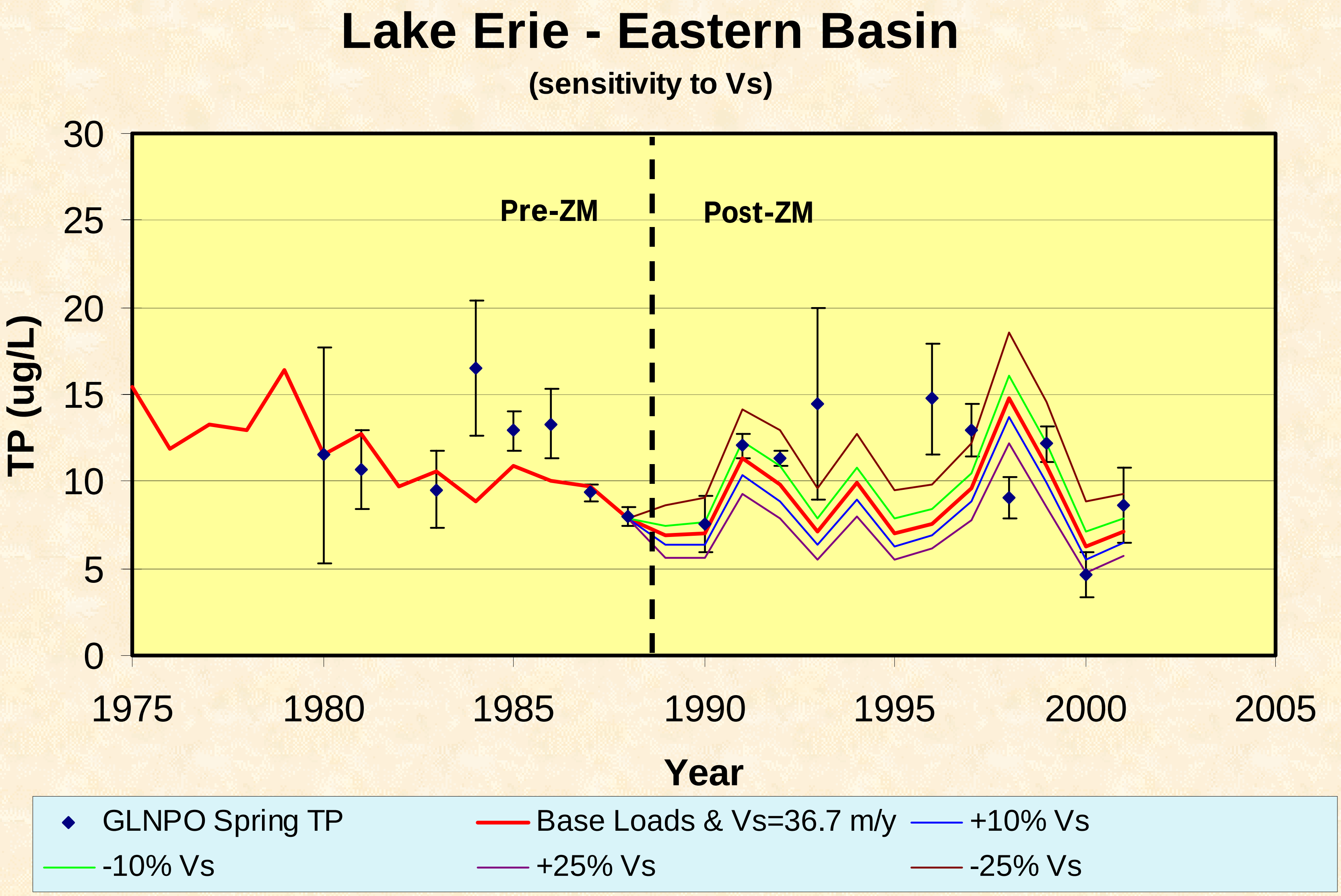
Model Sensitivity to Net Vs (WB)



Model Sensitivity to Net Vs (CB)



Model Sensitivity to Net Vs (EB)



Computer animation of model results:

-Starts in January, 1994

-Uses 2d currents from hydrodynamic model

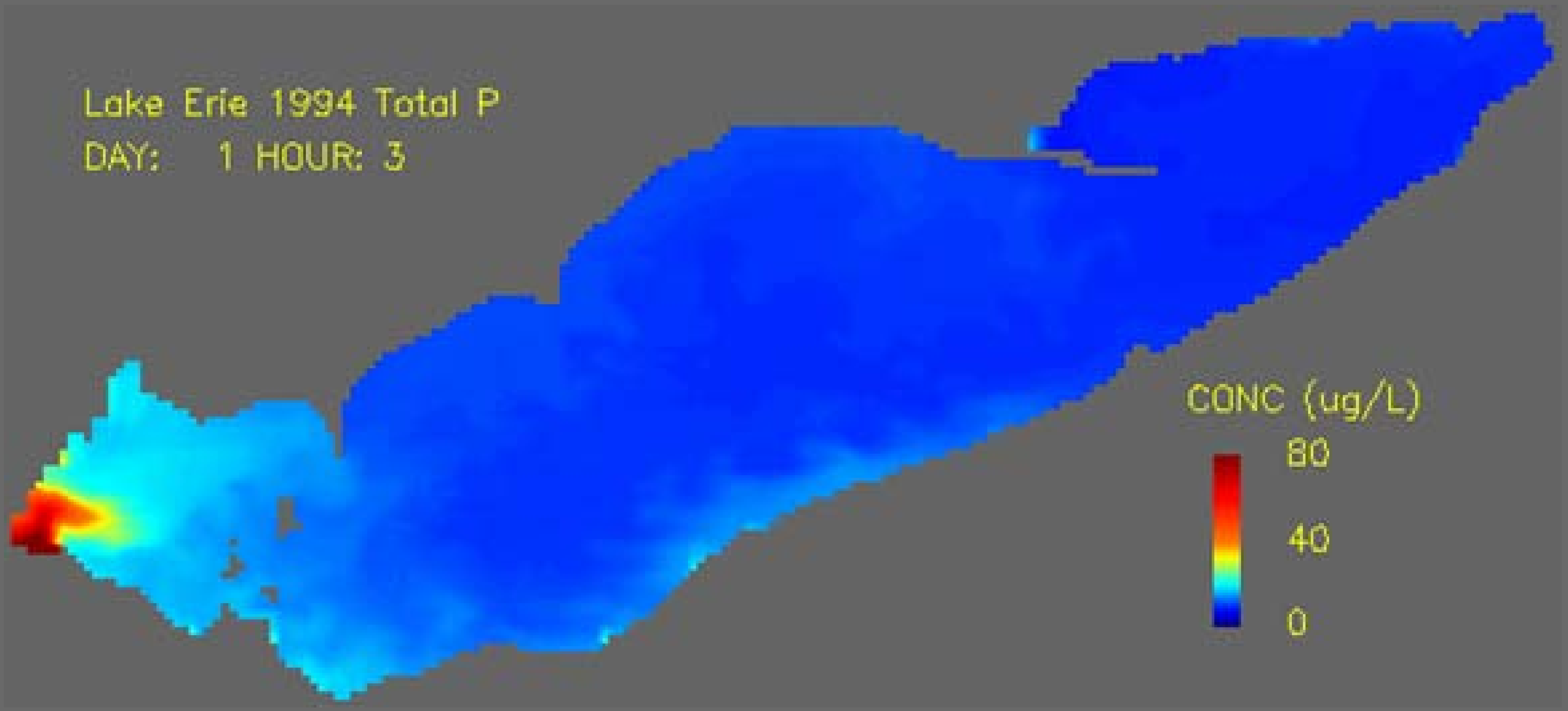
-Time dependent P loads

-Combination Lax-Wendroff and upwind advection scheme

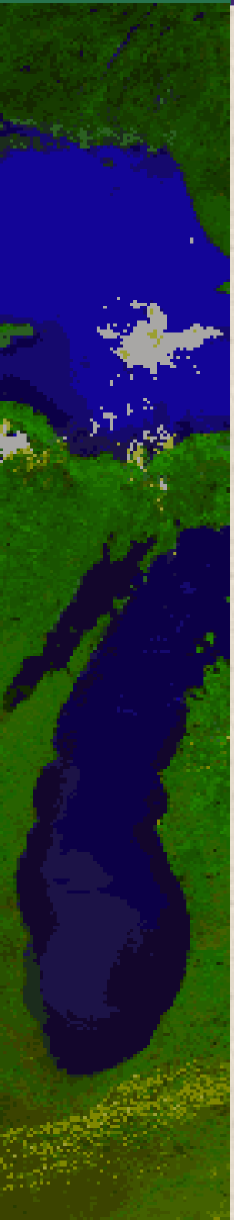
-No horizontal diffusion

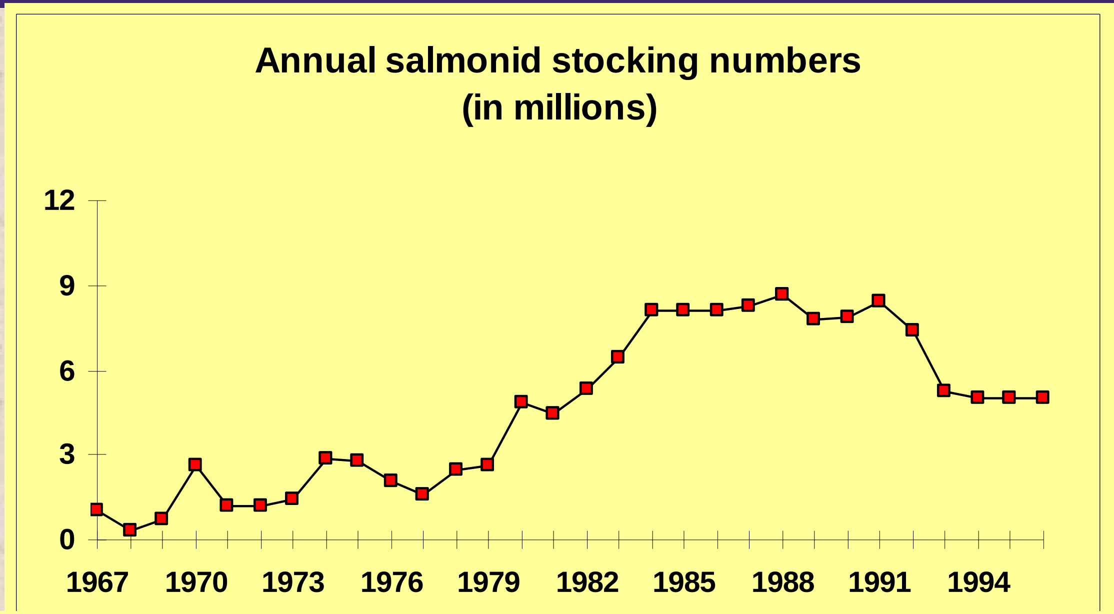
-Initial condition: C = 10 ug/L

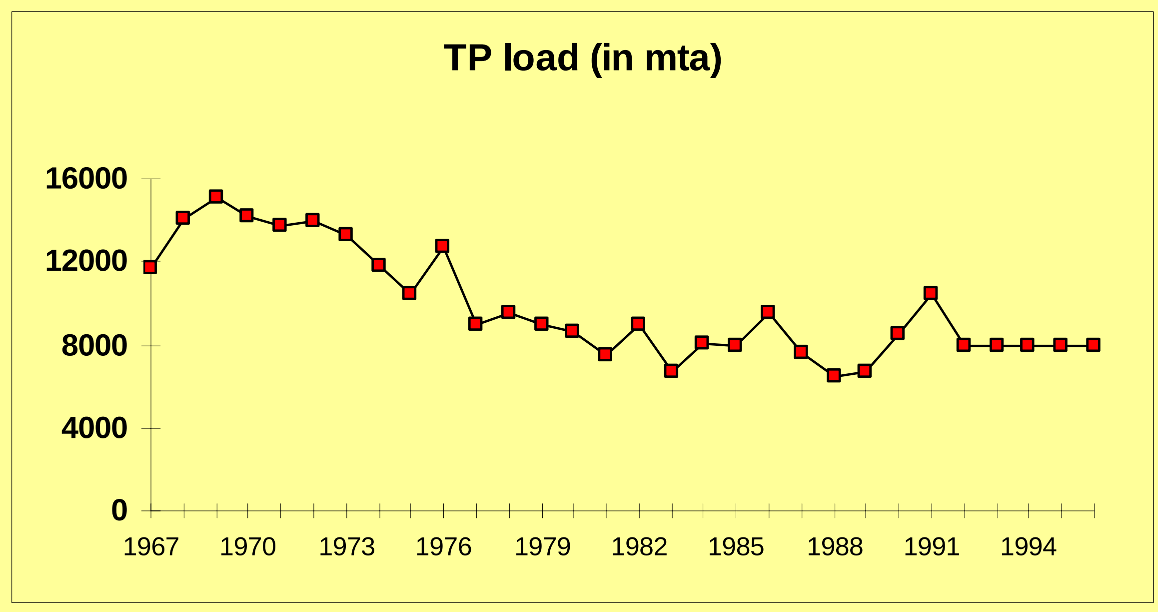
-Settling velocity = 6.8E-7 m/s (21 m/yr)



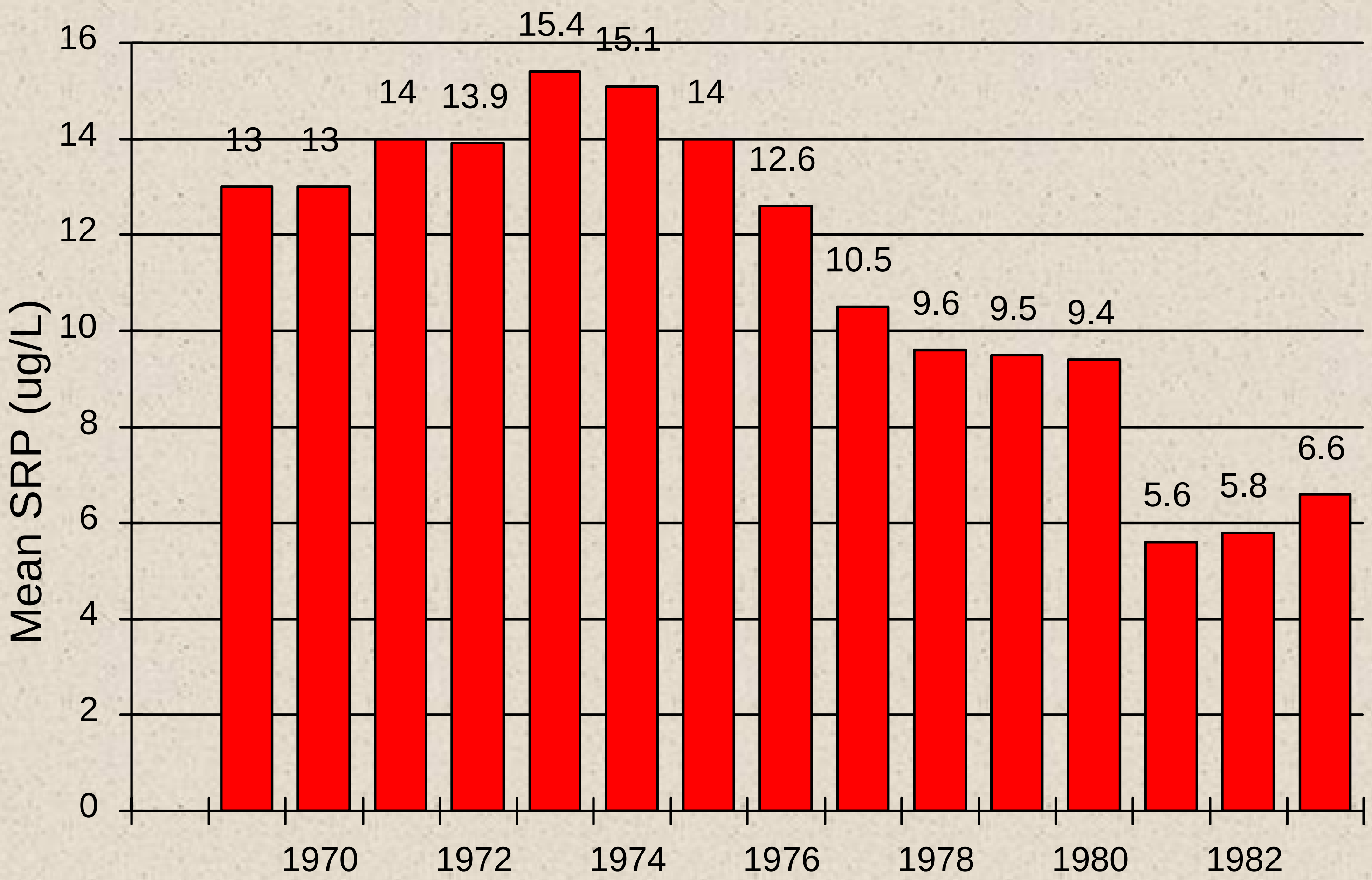
Historical Trends of Key Stressors in Lake Ontario





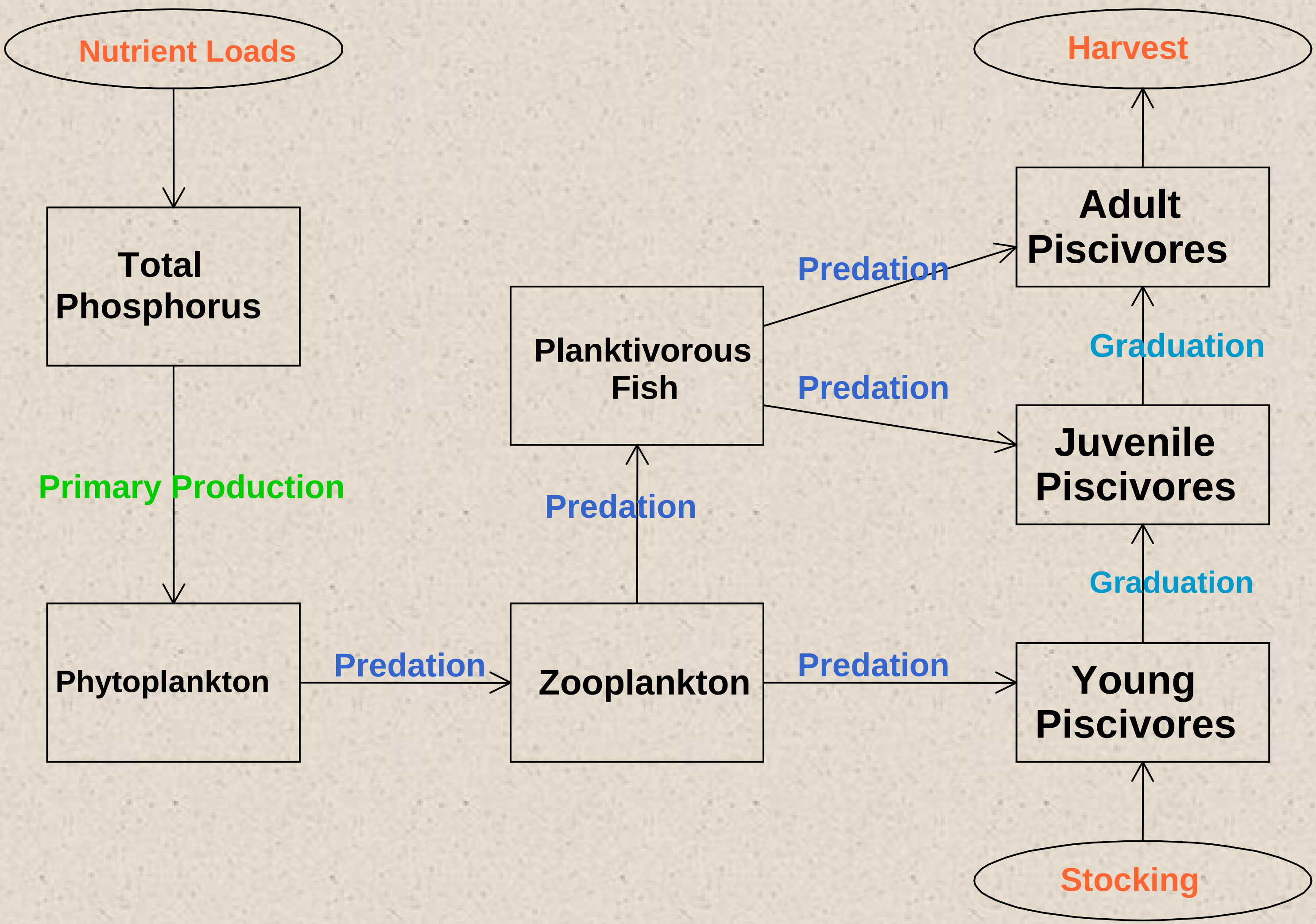


Spring Whole-lake Average SRP for Lake Ontario

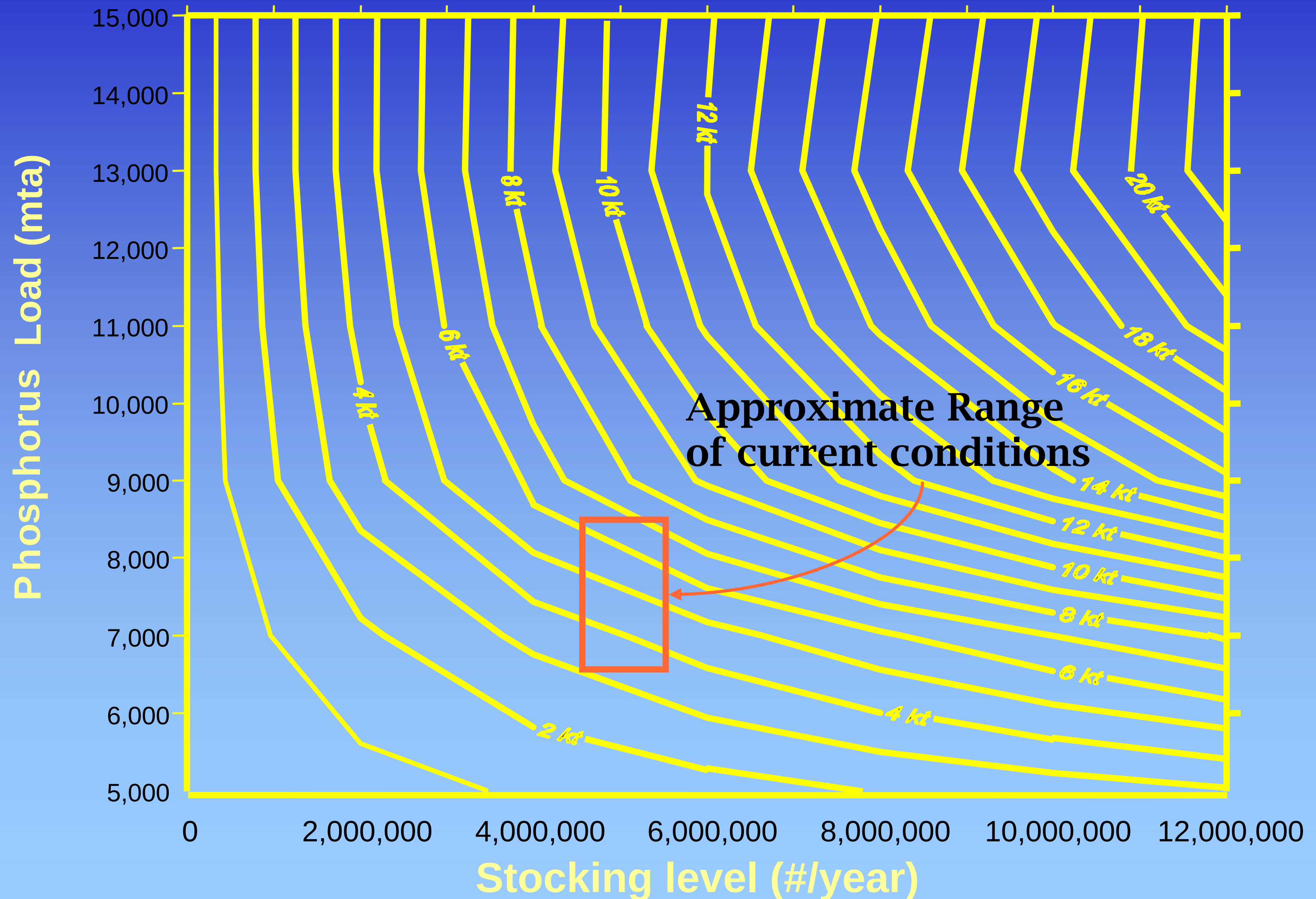


Nutrient Control versus Sport Fishing - Lake Ontario

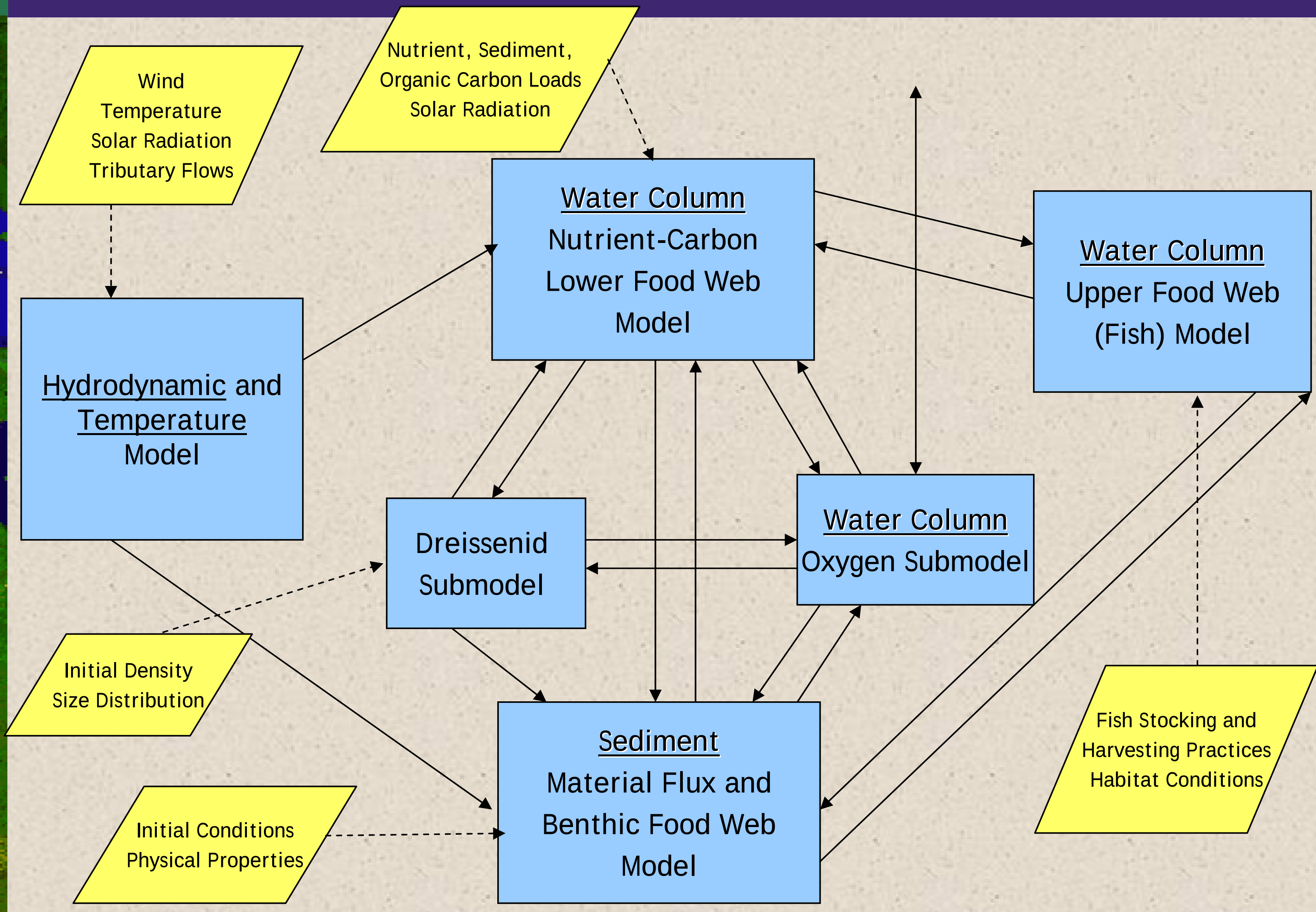
Conceptual Model of Simplified Lake Ontario Ecosystem Model



Adult Piscivore Biomass in Lake Ontario

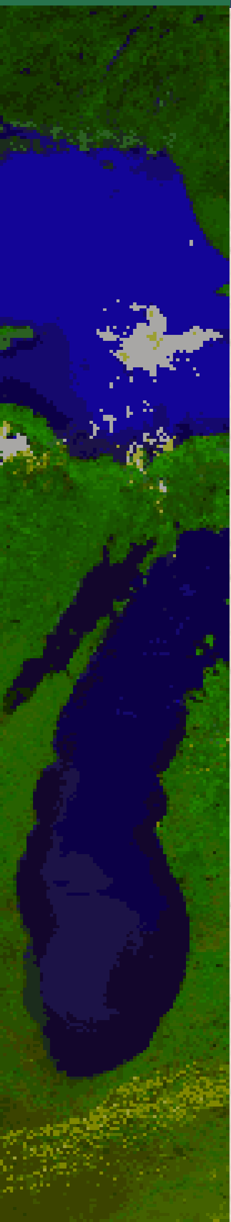


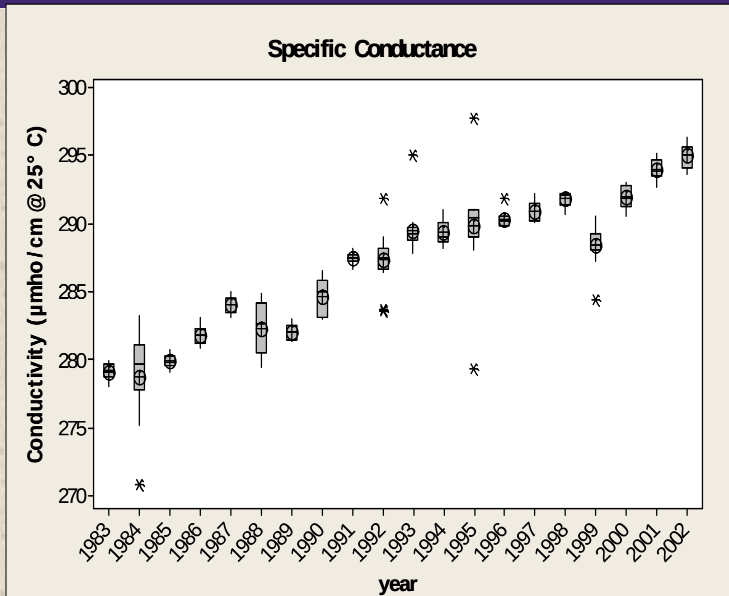
Model Linkages to P Management Questions

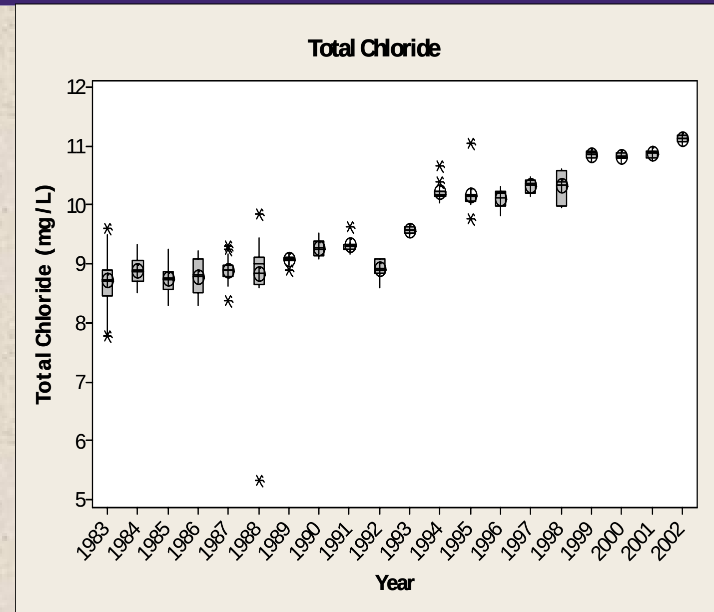


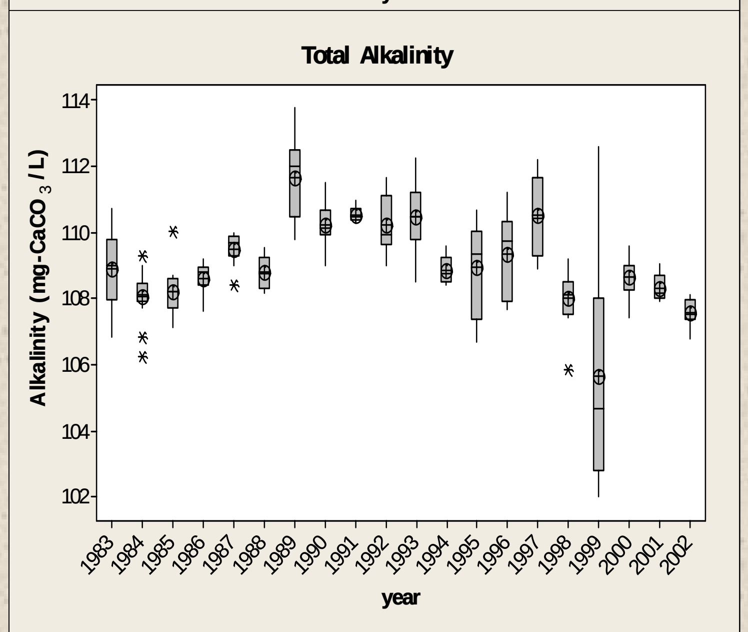
Lake Michigan Water Chemistry (1983-2002)

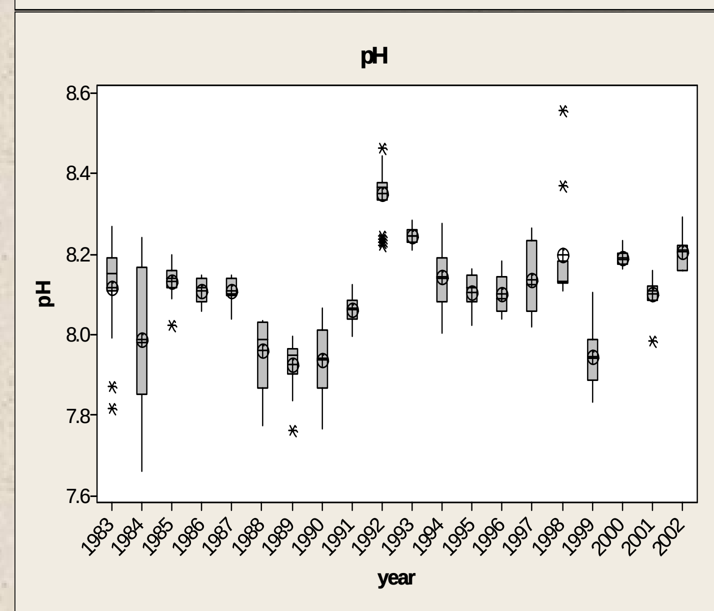
(GLNPO spring data)





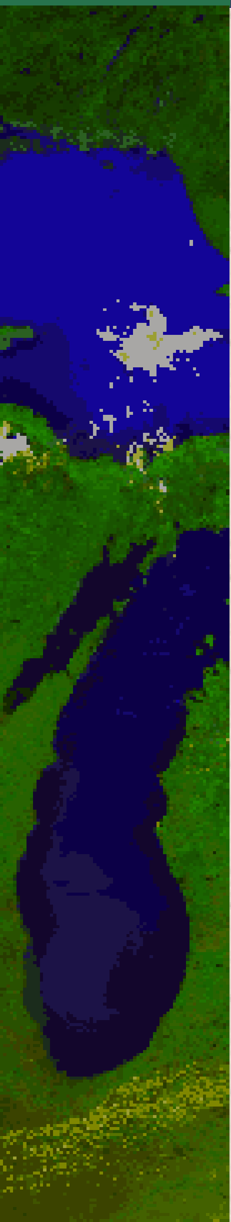


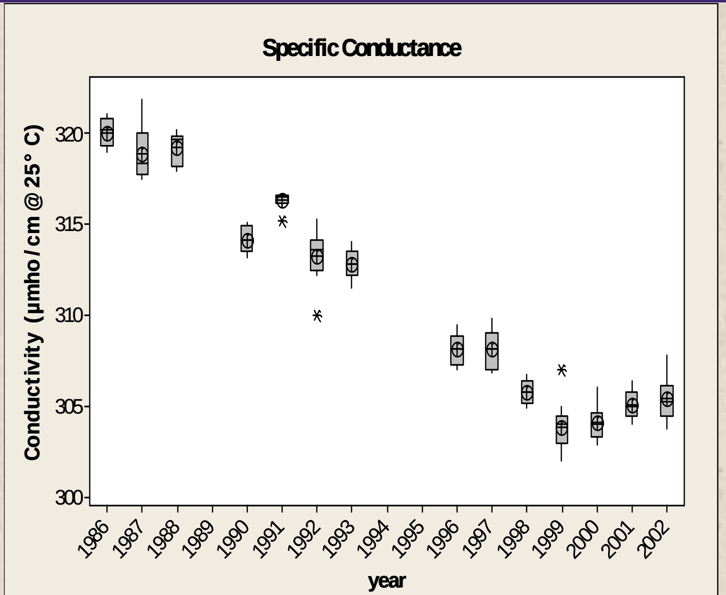


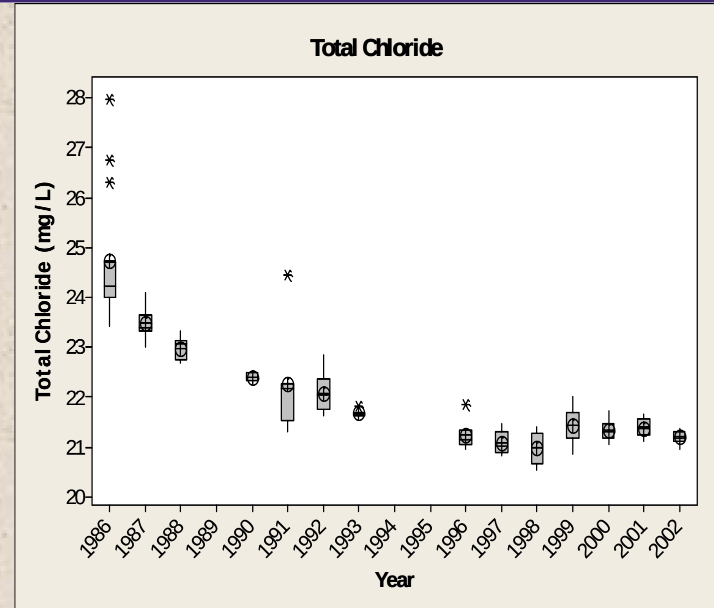


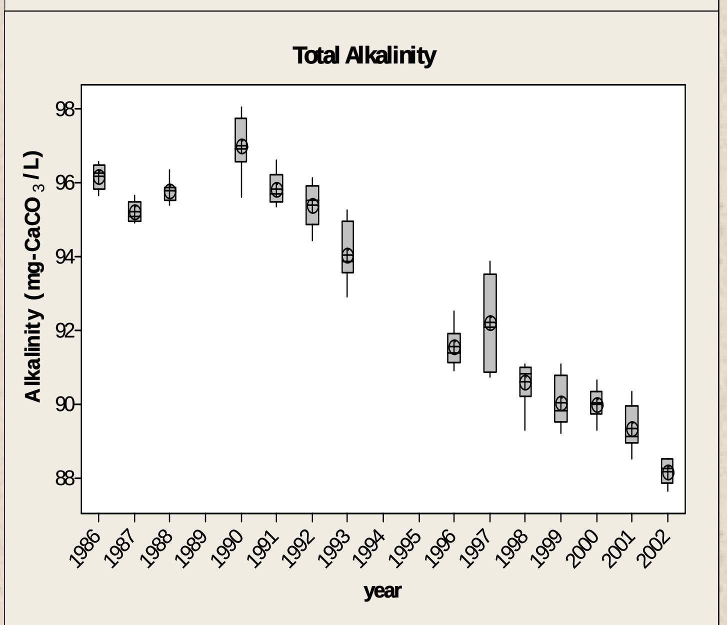
Lake Ontario Water Chemistry (1983-2002)

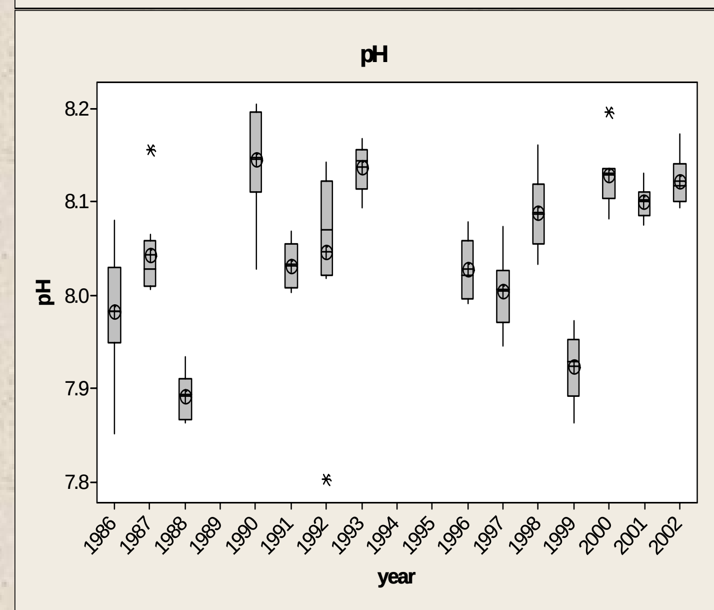
(GLNPO spring data)





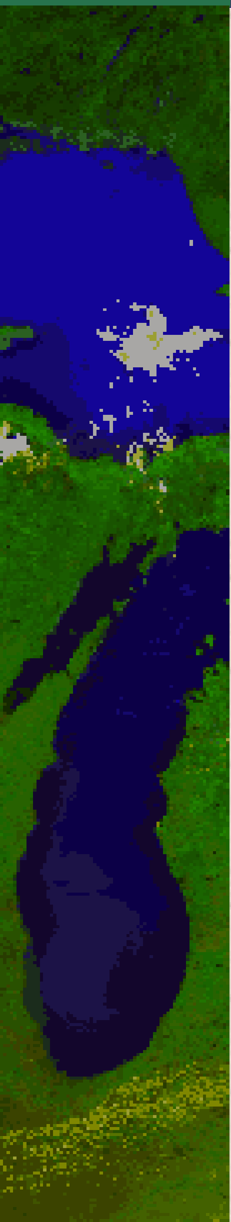


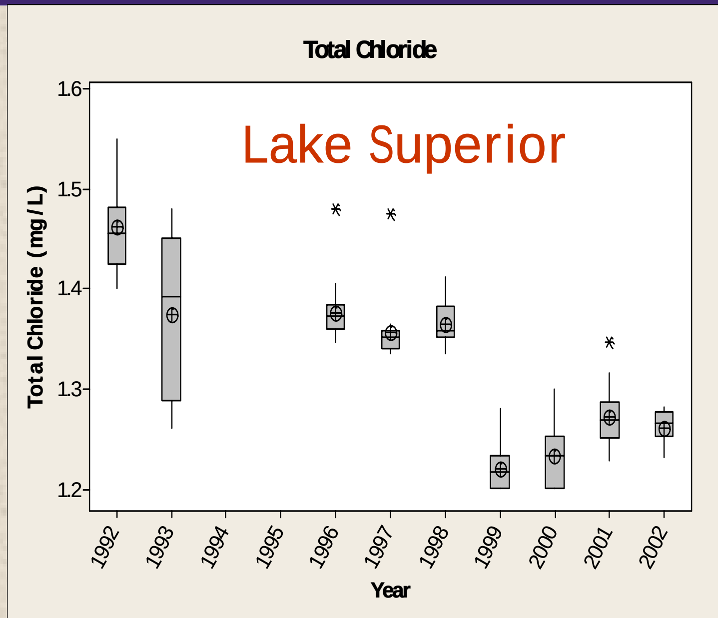


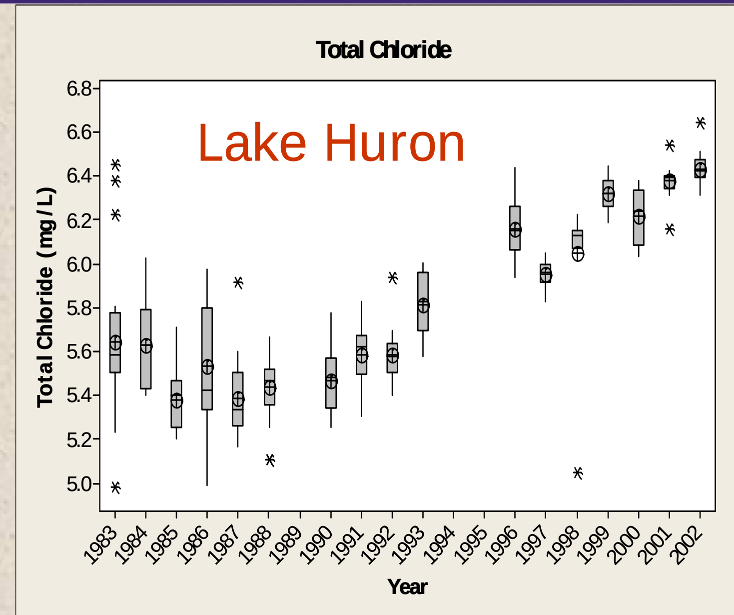


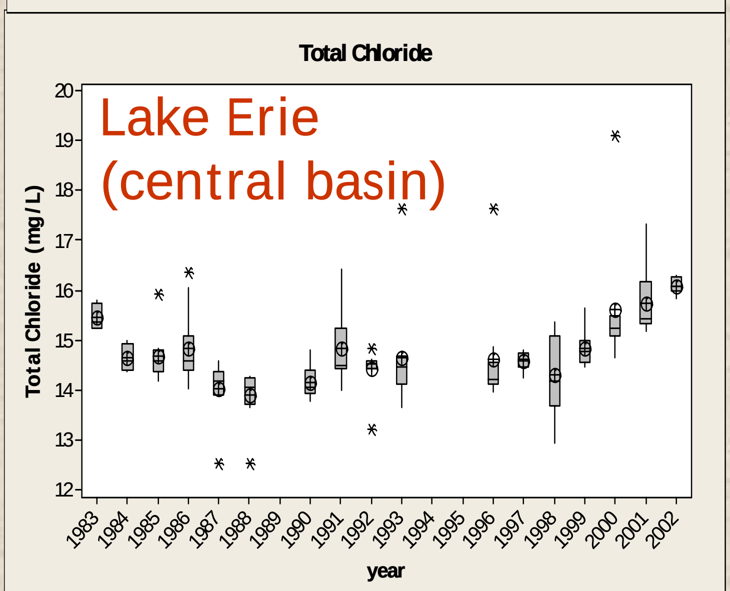
Chloride in Other Lakes (1983 – 2002)

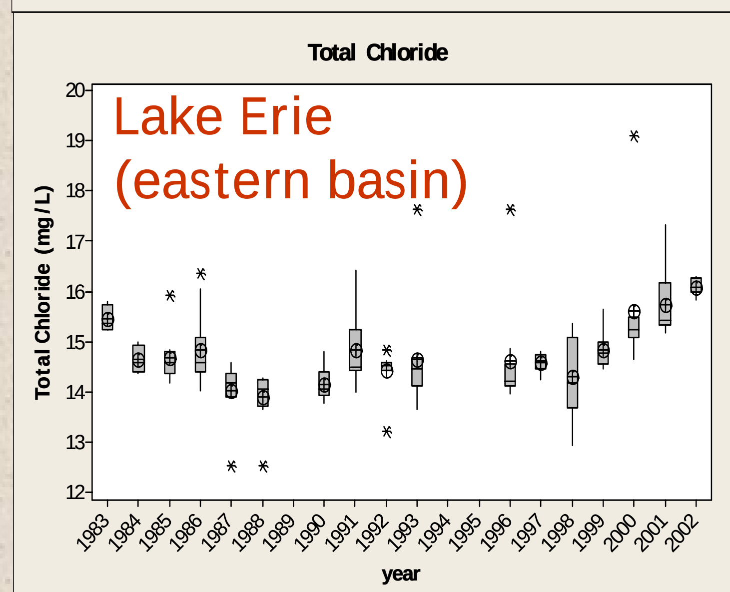
(GLNPO spring data)



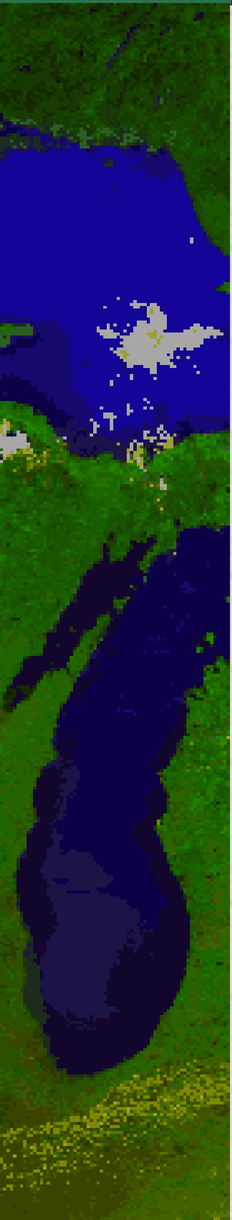






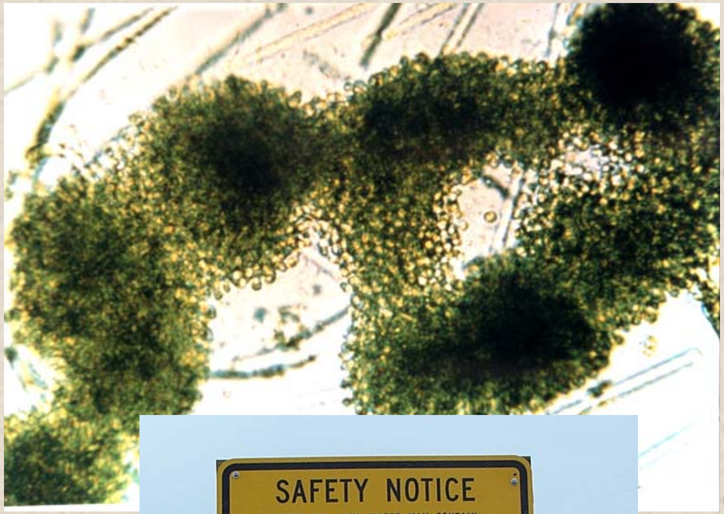


Cyanotoxins in the Lower Great Lakes



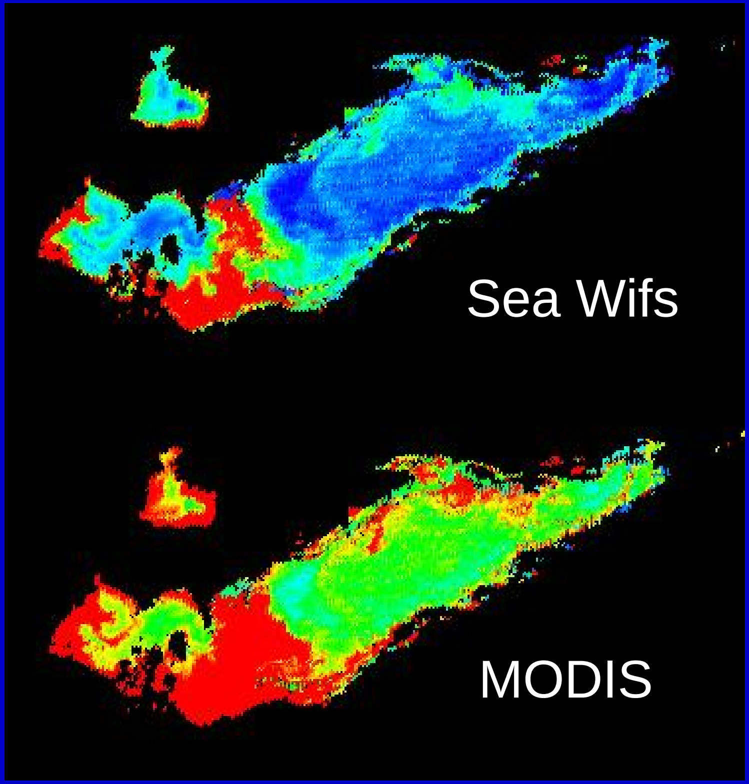
MERHAB-LGL
Harmful Algal Bloom
Monitoring and Event Response in the Lower Great Lakes

- **MERHAB-LGL Study**
  - PI: Greg Boyer, SUNY-ESF
- **Produced by cyanobacteria (blue-green algae)**
- **Four primary classes of toxin compounds**
  - Microcystin
  - Anatoxin-a
  - PSP toxins
  - Cynlindospermopsin
- **Neurotoxicity and hepatotoxicity in**
  - Fuana coming in contact with blooms
  - Can exceed WHO limits in drinking water intakes



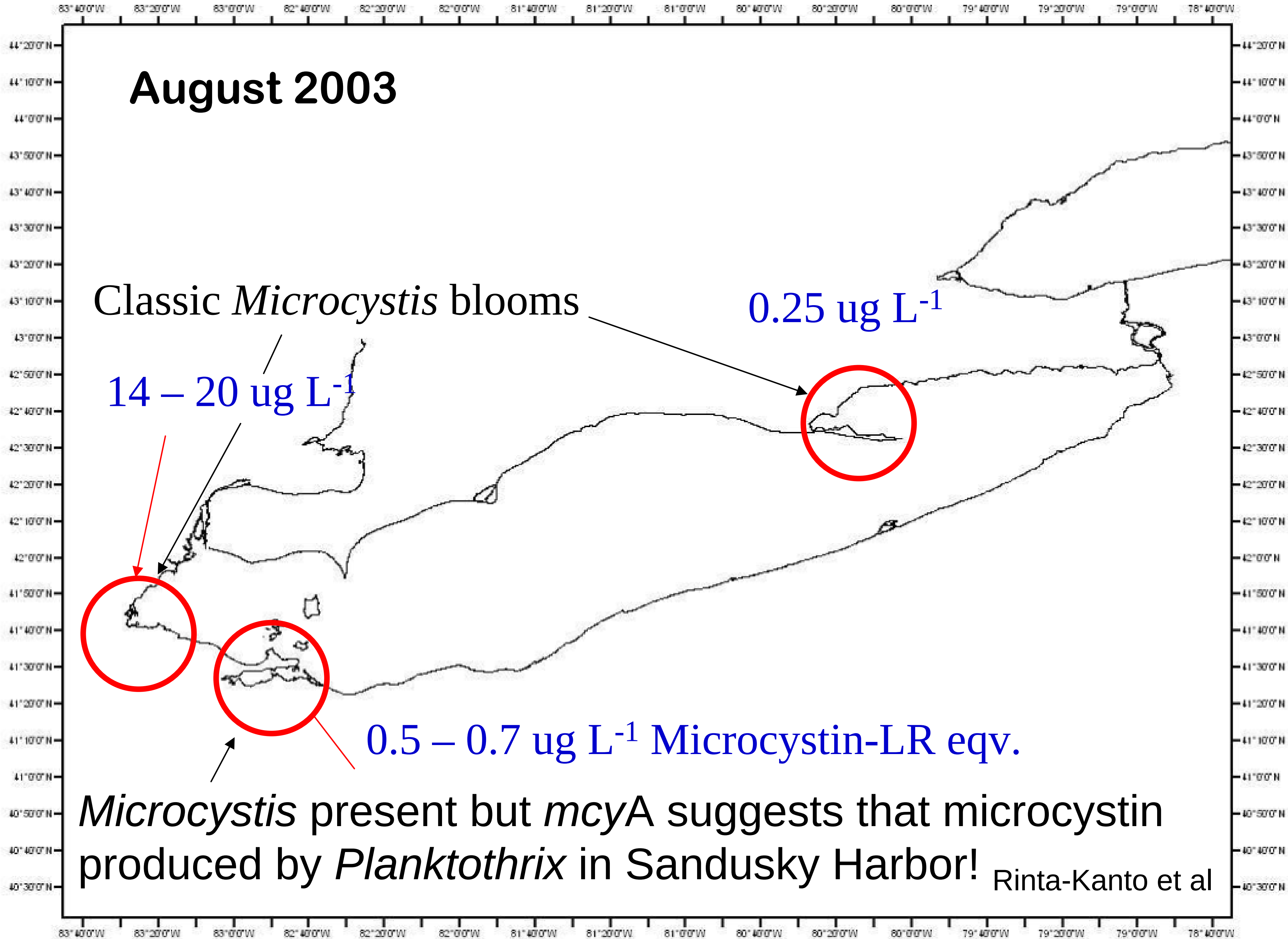
Cyanobacterial blooms are becoming commonplace in Lake Erie.

Lake Erie, August 23, '04



Imagery courtesy of M. Sultan, WMU

Year	(n)	% toxic >0.1 ppb	Highest value, ppb
1996 Sept	44	~10%	3.4
2002	119	7%	0.79
2003 July	59	41%	0.65
2003 Aug	48	60%	21
2004 July	40	38%	>1
2004 Aug	13	85%	2.4
2005	315	(3%)	0.27 (June)


August 2003
Classic *Microcystis* blooms
0.25 ug L-1
14 – 20 ug L-1
0.5 – 0.7 ug L-1 Microcystin-LR eqv.
Microcystis present but *mcy*A suggests that microcystin produced by *Planktothrix* in Sandusky Harbor!
Rinta-Kanto et al

Toxic Blooms in Lake Ontario

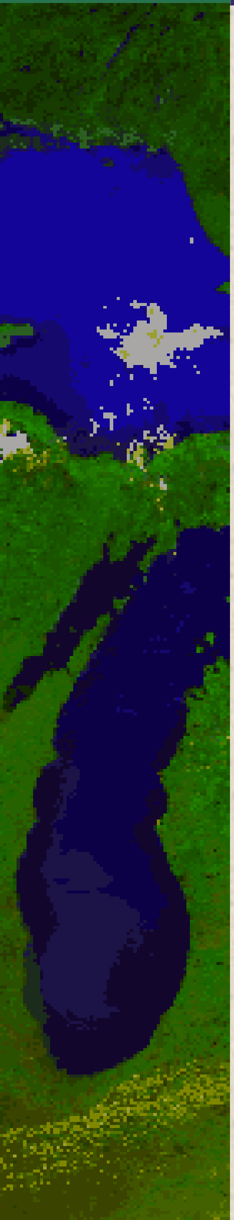
(not as severe as in Lake Erie)

Cruise date	# sta	Toxin ? (%)	Highest values	Notes
2000 (Aug)	2	0%	MC: < 0.02 $\mu g\ l^{-1}$	Eastern end
2001 (late July)	52	2% (MC) 4% (ATX)	MC: 0.15 $\mu g\ l^{-1}$ ATX: 0.05 $\mu g\ l^{-1}$	Whole lake
2002 (late June)	7	0% (MC) 70% (ATX)	MC: 0.007 $\mu g\ l^{-1}$ ATX: 0.006 $\mu g\ l^{-1}$	Henderson Bay
2003 (July, August)	80 63 17	>25% (MC) 0.5% (ATX)	MC: 1.06 $\mu g\ l^{-1}$ ATX: 0.01 $\mu g\ l^{-1}$	Whole lake + Eastern shore
2004 (Aug-Sept)	81	17% (MC) 16% (ATX)	MC: 0.85 $\mu g\ l^{-1}$ ATX: 0.02 $\mu g\ l^{-1}$	Whole lake

Clostridium botulinum

- **Bacterium that produces botulism toxin**
- **Anaerobic bacterium- it grows in the absence of oxygen**
- **Forms endospores- dormant structures that remain viable for years**
- **The endospores quite resistant to temperature extremes and drying.**

Where are the bacteria found?

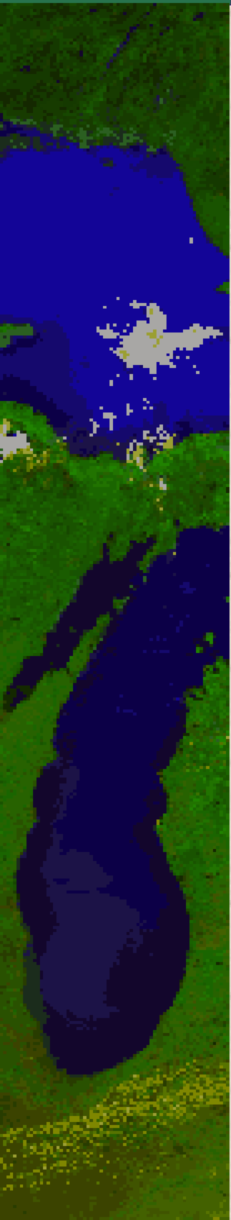


- Spores of both type C and type E Botulism are naturally found in anaerobic habitats:
    - Soils
    - Aquatic Sediments
    - Intestinal tracts of live, healthy animals

- In the absence of oxygen, with a suitable nutrient source, and under favorable temperatures and pH, spores can germinate and vegetative growth of bacterial cells can occur. (Brand, et. al 1988).

- Botulism toxin is only produced during vegetative growth, not when the bacterium is in its spore stage.

Botulism Outbreaks in Lower Lakes



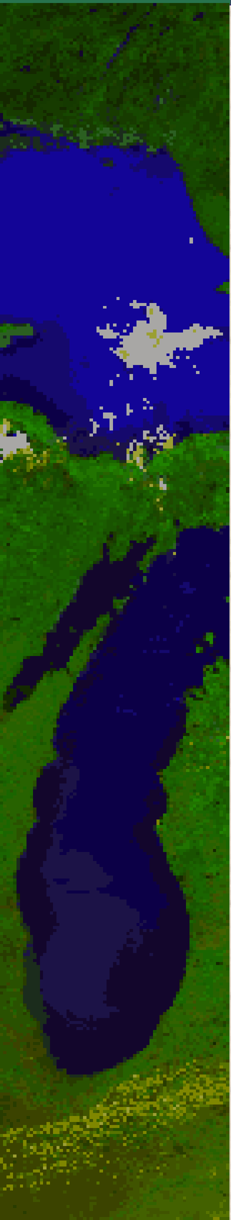
Lake Erie

- 1999-2002- Large Outbreaks
- Confined primarily to Eastern Basin
- Smaller Outbreak in 2003
- Minimal reports of fish mortality in 2004, but a larger die off of birds in November and December during migrations.
- Nov 3 - 15 (ongoing) approximately 200 Common Loons found at Long Point National Wildlife Area, Ontario.

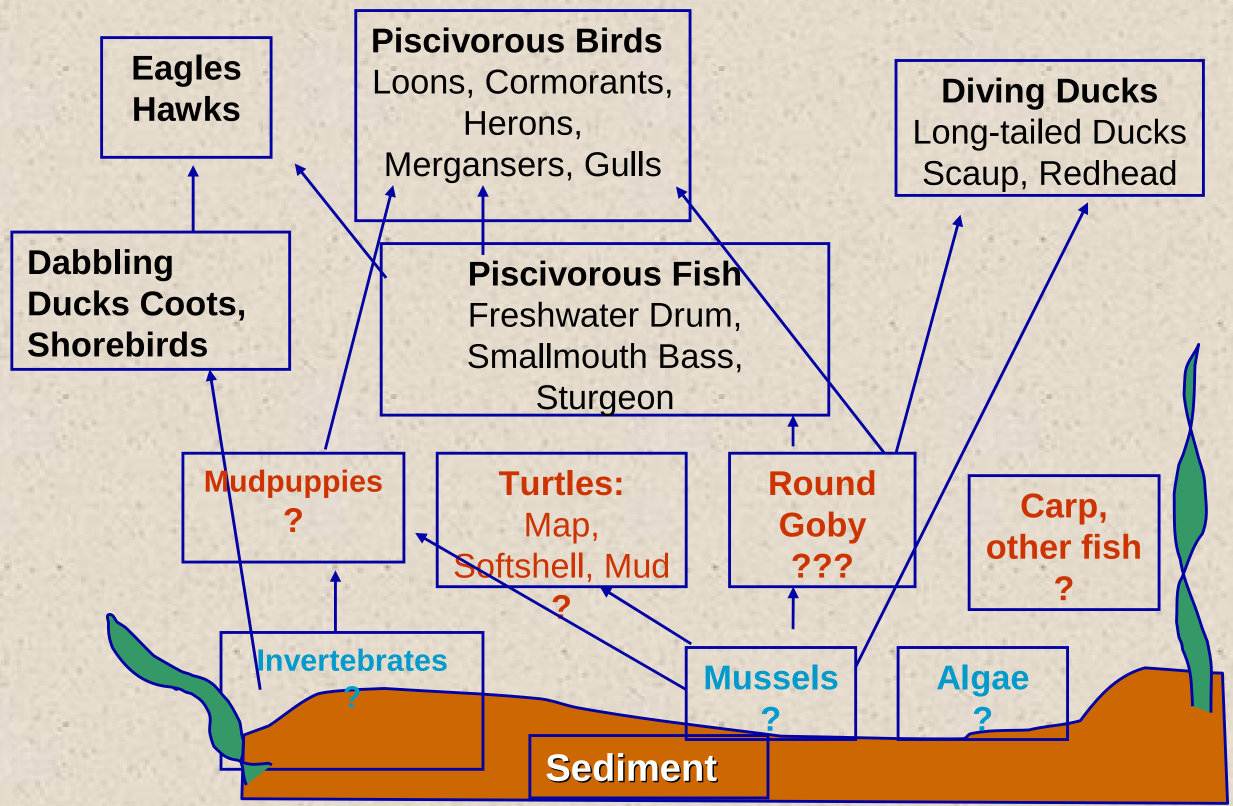
Lake Ontario

- 2003 – First small recorded outbreaks
- Outbreaks first confined primarily to Western Basin - some fish and birds
- 2004 - Outbreaks continued, birds and fish
- September 2004 - central portion of Lake Ontario, over 500 double-crested cormorants collected, tests were positive
- October 2004 - several hundred dead long- tailed ducks along the Hamilton/Burlington beaches
- Summer 2005 - over 1,400 double-crested cormorants collected on the islands along the Central-Eastern shore in Ontario.

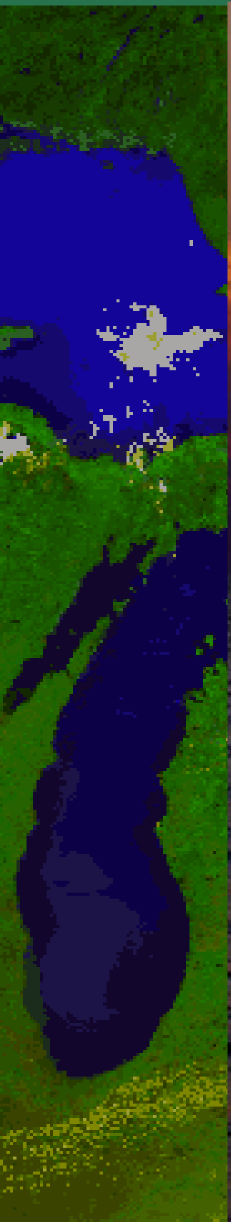
Botulism – Many unanswered questions



- Is the outbreak caused by a new strain?
- Do algae blooms (Cladophora) play a role?
- Do Dreissenids play a role?
- Why have fish die-offs decreased since 2003?
- Is the decrease related to goby populations?



Lessons



- Ecological integrity cannot be achieved simply by managing chemical integrity
  - Physical and biological integrity matter
  - Scale matters
- Cannot understand chemical integrity in an ecological vacuum
  - Ecosystems have many feedback mechanisms that provide resilience; these must be understood in order to define bounds of chemical integrity
- Ecological integrity cannot be achieved by managing single issues independently of understanding interactions with other management issues
- Require coordinated modeling, monitoring, and research programs
- If we have learned anything over the last 30 years, it is that we need a *Great Lakes Basin Ecosystem Agreement*